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Maryland Aquatic Nuisance Species Management Plan

DRAFT
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Pending approval by the Aquatic Nuisance Species Task Force

This Aquatic Nuisance Species Management Plan was prepared by the Maryland Department of Natural Resources Invasive Species Matrix Team in partnership with Maryland agencies and organizations invested in invasive species management, and with input from the general public.

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State of Maryland
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Signature Date

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ACKNOWLEDGMENTS

DRAFT

MARYLAND AQUATIC NUISANCE SPECIES MANAGEMENT PLAN

EXECUTIVE SUMMARY

An aquatic nuisance species (ANS) is a non-native species whose introduction does or is likely to cause economic or environmental harm or harm to human health. While many aquatic species may be introduced to a water body, very few become established, and fewer are regarded as ANS. In the Chesapeake Bay watershed, there are 120 introduced and established aquatic species (mostly fishes) listed by United States Geological Survey. Eighteen percent of these are regarded as ANS and threaten business in the State. Current initiatives to prevent future introductions and control the current spread of ANS include:

- Formation of the Maryland Department of Natural Resources Invasive Species Matrix Team;
- Development of Management Plans for targeted species by the Chesapeake Bay Program;
- Increased education awareness by working with K-12 schools and developing on-line websites; and,
- Incentives for controlling ANS with invasive species state records, raffles and contests by Maryland Department of Natural Resources.

These efforts have been successful, but there is a lack of coordination among agencies within the State to improve upon the effectiveness of these programs. Funding these initiatives and others is also not sufficient.

Purpose

- Help gain funding from private or State and Federal sources to prevent and control the spread of ANS in the State;
- Create a collaborative team of State and Federal agencies and the public to develop, cost-effective ANS population control approaches; and
- Provide tools for managers and the public to assess intentional introductions allowed by government into Maryland and rapidly respond to unintentional or unauthorized ones.

Goal

Fully implement a coordinated strategy that minimizes risk of establishment by ANS along known pathways by 2020 and when possible, stop the spread of ANS in Maryland and eradicate or control ANS to a minimal level of impact.

Objectives

- Prevent new and additional introductions of ANS to Maryland waters;

- Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species; and

- Control and slow the spread of existing ANS in Maryland.

Actions to Achieve Objectives

- Develop greater coordination with neighboring state agencies regarding ANS;
- Review and update lists of prioritized ANS;
- Conduct risk assessments for prioritized ANS;
- Rank prioritized ANS according to risk;
- Use pathway analysis to rank pathways of introduction;
- Provide results of risk assessments, pathway analysis and ranks online;
- Assess existing laws and regulations to determine their adequacy for preventing introduction or spread of ANS;
- Restore ecosystems impacted by ANS using native species, when necessary;
- Create outreach and teaching materials in appropriate languages for targeted stakeholder groups;
- Identify, describe, adopt, use and periodically review a reporting database for ANS in Maryland;
- Develop a social media platform to assist the public in reporting new species occurrences to the Department of Natural Resources;
- Adopt and train individuals to use a Rapid Response Plan for Maryland, the *Rapid Response Planning for Aquatic Invasive Species: A Template*, published by National Oceanic and Atmospheric Administration;
- Conduct and review studies to determine the most effective tools for removing ANS;
- Work with stakeholders to create laws or regulations, training materials and programs, and control strategies aimed at preventing spread of ANS; and,
- Identify funding sources to carry out these actions.

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GLOSSARY[1]

Aquaculture: The rearing of aquatic animals or the cultivation of aquatic plants for food.

Aquatic Nuisance Species and **Invasive Species**: Considered synonymous terms for this plan, these are non-native species whose introduction causes, or is likely to cause, economic or environmental harm or harm to human, animal, or plant health (Beck et al. 2008). The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, authorized by United States Congress, defines an aquatic nuisance species as a nonindigenous species that threatens the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural, or recreational activities dependent on such waters (ANSTF 1994). The term ANS is often used interchangeably with aquatic invasive species, the preferred term of Federal and State managers.

Aquatic Species: A species that is totally or mostly dependent on aquatic ecosystems for a significant portion of their life cycle (ANSTF 1994).

Ballast: Heavy material, such as gravel, sand, iron or lead, placed low in a vessel to improve its stability.

Bilge: The lowest internal compartment on a ship or boat where water collects from the surrounding environment.

Control: The restriction of an activity, tendency, or phenomenon, which includes the spread of aquatic nuisance species.

Environmental Harm: Biologically significant decreases in native species populations, alterations of plant and animal communities, or changes in ecological processes that native species and other desirable plants and animals and humans depend on for survival (National Invasive Species Council, *Invasive species definition clarification and guidance white paper*, 2006).

Established: Having been in existence for a long time, such as a population that naturally persists in an environment.

Exotic: Originating in or characteristic of a distant foreign country. Also known as nonindigenous or non-native.

High Priority: For the purpose of this ANSP, established species or species groups for which there is a high probability of negative economic and/or ecological impact. These species can include: *Hydrilla*, northern snakehead, blue catfish, flathead catfish, zebra mussel, Asian clam, green crab, some non-native crayfishes, and didymo.

[1] Unless otherwise referenced, definitions were obtained from the 2015 Oxford Dictionary, Oxford University Press.

Indigenous: Originating or occurring naturally in a particular place; also known as native.

Introduction: A thing (or species) newly brought to a place for the first time. The intentional or unintentional escape, release, or placement of a species into an ecosystem as a result of human activity constitutes an introduction.

Low Priority: For the purpose of this ANSP, established aquatic species that occur in Maryland waters for which there are neutral or beneficial economic and/or ecological impact. These species are not considered ANS by this ANS Management Plan. These species include: trout species, triploid grass carp, hybrid sunfish, and largemouth bass.

Macroinvertebrate: A macroscopic invertebrate, especially one whose shortest dimension is greater than half a millimeter and large enough to be visible to the human eye.

Mollusks: An invertebrate of Phylum Mollusca including snails, clams, mussels and squid that have soft, unsegmented bodies, live in aquatic habitats, and typically possess a mantle and a shell.

Native: An animal or plant indigenous to a place, such as those that occurred pre-colonially or occurs in a particular ecosystem other than as a result of introduction.

Non-native: Synonym for exotic, nonindigenous, or alien. In Federal executive order 13112, the term *alien species* is defined as any species, including seeds, eggs, spores, or other biological material capable of propagating that species, that is not native to that ecosystem.

Nuisance Species: A species that causes inconvenience or annoyance, synonymous with invasive species and aquatic nuisance species for the purpose of this Plan.

Pathogen: A bacterium, virus, or other microorganism that can cause disease.

Pathway: Any means that allows entry or spread of an invasive species (Campbell and Kriesch 2003), which may include a single or series of methodological steps that lead to the introduction of a non-native species.

Propagule Pressure: The number of introductions per unit time, which may include the number of individuals of a species, the number of taxa or genotypes introduced, or number of introduction events (Richardson and Pysek 2011). Encompasses variation in quantity, composition, and rate of supply of non-native organisms to a recipient region. The release of hundreds of individuals periodically over a decade or the release of a few individuals monthly the same period could yield the same propagule pressure.

Rapid Response: A systematic effort to eradicate, or contain ANS while infestations are still localized (NISC 2008). The Mid-Atlantic Panel on Aquatic Invasive Species (MAP) produced a Rapid Response Plan to foster a timely, thorough response to unauthorized, intentional or unintentional introductions of non-native ANS. The most effective efforts to control newly introduced organisms are those which are mounted soon after introduction. An appropriate response may be initiated simply by providing continual outreach that encourages the public to report and remove a recognized non-native and aquatic nuisance species.

Red Alert Species: For the purpose of this ANSP, aquatic nuisance species that are not established or do not yet occur in Maryland waters, but may occur in the future because of human introduction or natural range extensions. These species have a high probability of negative, economic and/or ecological impact, but may have risk assessments or management plans for regions of their occurrence. Examples of these species include silver carp and lionfish.

Stakeholder: A person or organization with an interest or concern in something, and can include local, county, regional, state, or federal governments, along with non-governmental organizations and the general public.

State partners: All partners within Maryland working toward the common noted in this Aquatic Nuisance Species Plan; listed partners are included in Appendix 2.

Taxa: The plural of taxon, which is a taxonomic group of any rank to classify organisms (e.g., kingdom, phylum, class, order, family, genus, species).

Unknown Priority: For the purpose of this ANSP, aquatic species established in Maryland without any natural history information to allow for a reasonable determination as to a low or high priority status. For unknown priority species, it may be prudent to consider them high priority and ANS until evidence states otherwise.

Vector: A type of pathway of introduction (http://www.anstaskforce.gov/ans.php, accessed December 2015), or the physical means that a species is transported into ecosystem.

Watershed: An area or ridge of land that is drained by a river, river system, or other body of water.

ACRONYMS

ANS	Aquatic Nuisance Species
ANSP	Aquatic Nuisance Species Management Plan
ANSTF	Aquatic Nuisance Species Task Force
CBP	Chesapeake Bay Program
ISMT	Invasive Species Matrix Team
IMO	International Maritime Organization
MAIPC	Mid-Atlantic Invasive Plant Council
MAPAIS	Mid-Atlantic Panel of Aquatic Invasive Species
MDA	Maryland Department of Agriculture
MDE	Maryland Department of the Environment
MDDNR	Maryland Department of Natural Resources
MDSG	Maryland SeaGrant
NANPCA	Nonindigenous Aquatic Nuisance Prevention and Control Act
NISA	National Invasive Species Act
NISC	National Invasive Species Council
USCG	United States Coast Guard
USGS	United States Geological Survey
USFWS	United States Fish and Wildlife Service

INTRODUCTION

The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA), reauthorized with the passage of the National Invasive Species Act (NISA) in 1996, defines an aquatic nuisance species (ANS) as a nonindigenous species that threatens the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural or recreational activities dependent on such waters. The term ANS is often used interchangeably with aquatic invasive species, which is the preferred term of Federal and State governments. While a State Plan to manage terrestrial nuisance species may be forthcoming, the content of the current Plan regards only species that spend the majority of their life cycle in aquatic habitats.

Numerous exotic species have been introduced across the globe, intentionally by government and non-government agencies using fish stocking or biological control initiatives and unintentionally from ballast water transfer or public release; some of these species are now regarded as ANS. In Maryland, these ANS can include: *Hydrilla*, zebra mussel, blue catfish, flathead catfish, and northern snakehead (Appendix 1).

Plan Purpose

Purpose of the Maryland Aquatic Nuisance Species Management Plan (ANSP) is to unify stakeholders such as agencies, general public, and industries, and to more effectively coordinate activities aimed at preventing new introductions and controlling the spread of current ANS. An ANSP for Maryland will help leverage funding from private or State and Federal sources to both prevent and control the spread of ANS in Maryland by determining the pathways of introduction, identifying ANS among those pathways, and organizing a collaborative team of State and Federal agencies and the public to develop creative, cost-effective approaches toward ANS population control. It will also provide tools for natural resource managers and the public to objectively assess introductions allowed by government into Maryland and rapidly respond to unintentional ones. The ANSP will be routinely evaluated for completion of actions in the implementation table.

Geographic Scope of Plan

Much of Maryland lies within the Chesapeake Bay watershed. The Chesapeake Bay watershed is the largest estuary in the United States (64,000 km^2), and contains major shipping routes in two of the most populous cities in the nation (Baltimore, MD and Washington, D.C.). The watershed is also interconnected with the Delaware River by the Chesapeake and Delaware (C&D) Canal and receives drainage from Washington D.C. and 6 states: Maryland, Virginia, Delaware, West Virginia, Pennsylvania, and New York.

Maryland has no natural lakes, but contains several large impounded waterways that are popular tourist destinations for out-of-state visitors. As a result of its vast drainage area and its interconnections with other watersheds, the Chesapeake Bay watershed may be colonized by ANS that naturally disperse from other state waters or directly into Maryland waters from introductions.

While the Chesapeake Bay watershed is the largest watershed in Maryland, there are two other watersheds that must also be considered: the coastal bays watershed and the Youghiogheny River (Figure 1). The coastal bays watershed includes 5 coastal lagoons and tributaries that drain into them. The lagoons are generally brackish, with natural corridors to the Atlantic Ocean through the Ocean City Inlet to the north and Chincoteague Inlet (in Virginia) to the south. The Youghiogheny River drains a portion of western Maryland and is shared by West Virginia and Pennsylvania. It is a non-tidal stream that drains from Maryland into the Ohio River Basin, which drains into Mississippi River drainages.

Many of Maryland's water bodies are interconnected by canals that may increase propagule pressure and should be managed in some cases (Smith and Tibbles 1980; Daniels 2001). The hydrology of canals and dispersal corridors could change as climates and land usage change, leading to greater expansion of ANS. Increased precipitation and stream flow is expected to result from climate change in the Chesapeake Bay watershed (Najjar et al. 2010) and will serve to better connect otherwise isolated, adjacent drainages and could lead to the spread of ANS among drainages. In addition, annual averages in water temperature are more likely to increase than decrease in the Chesapeake Bay watershed (Wood et al. 2002). Increased water temperatures could also lead to natural range expansions for more tropical ANS, such as lionfish. The consideration of climate change in risk assessment is improving among state agencies (EPA 2008), but complicated because consequences of climate change are complex.

The Maryland ANSP addresses pathways and ANS for all waters in Maryland, including the three watersheds (Youghiogheny, Chesapeake, coastal bays) and shared waters with neighboring states such as Potomac River (Maryland, Virginia, West Virginia), Nanticoke River (Maryland, Delaware), and Conowingo Reservoir (Maryland, Pennsylvania). The largest watershed that is contained by Maryland is Chesapeake Bay watershed. The coastal bays watershed is the second largest. Currently there are no data that indicate whether a particular watershed should be prioritized for action items noted here.

ANS Plans for Neighboring Jurisdictions

There is an existing ANS Management Plan for the State of Virginia, Pennsylvania, and New York. An ANS Management Plan for West Virginia is currently under development. Currently, the State of Delaware and Washington D.C. do not have ANSPs. Coordination among agencies and jurisdictions was accomplished with USFWS leadership to restrict live possession of Northern Snakehead. However, many other species and pathways have not been jointly and similarly regulated (e.g., blue catfish or mandating boat cleaning before launch). There are two organizations in which these states participate to address invasive species: Mid-Atlantic Invasive Plant Council (MAIPC) and Mid-Atlantic Panel on Aquatic Invasive Species (MAIPIS). During routine meetings of these organizations, coordination of actions related to various state ANS plans are discussed. In addition to ANS plans, Maryland has several individual plans that pertain to a species or group of species. These specific plans are referenced in *HIGH PRIORITY PATHWAYS AND ANS* in this ANSP. Action items of those plans are similar to those given here.

Gaps and Challenges

While a regional rapid response plan exists (Smits and Moser 2009), a comprehensive statewide plan has not been approved by the Aquatic Nuisance Species Task Force. A major challenge in implementing a comprehensive statewide plan is in establishing a framework for all authorities who are involved in ANS management (Appendix 2) to jointly discuss ANS issues. The MDDNR ISMT integrates several authorities, but requires long-term stability and greater participation from other authorities. These authorities may identify gaps in laws and regulation that could prevent ANS introduction. Recent statewide increases in fines were adopted for people violating existing ANS regulation and law. Additionally, a recent law was passed to fine boaters who launch vessels that are fouled with organic material, to public waters. New regulations and laws may additionally become necessary as new pathways of introduction are identified. However, even existing laws and regulations to prevent bait introductions or possession of certain ANS are not easily enforced and require more education and outreach with stakeholders (e.g., bait dealers) to become effective.

Apathy regarding introduction of species may stem from a general misunderstanding of potential impacts of ANS introduction. There are gaps in existing knowledge on the impacts of many ANS within Maryland waters. In recent years, for example, gaps in understanding the ecological role of northern snakehead and blue catfish have led to widespread concern for natural resources that the State aims to protect, such as shad and largemouth bass. It has also led to apathy of some anglers and in some cases, a desire to manage these species as important game fishes. Other ANS such as green crab and zebra mussel have not yet demonstratively impacted Maryland's ecosystems, though these species have caused problems for other non-indigenous regions where they thrive. To institute a control program that cost-effectively minimizes negative impacts from ANS, the negative impacts from ANS must be well-documented. Of 22 high priority ANS, only 7 have Maryland management plans that emphasize both impacts and the control needed to minimize impacts (see High Priority and Red Alert Species, below).

There are larger gaps in assessing risk of the establishment and invasiveness of species that are not yet in Maryland waters and some of these are red alert species. Many pathways are known to transmit species into Maryland waters and potential species include silver carp and non-native crayfishes. In addition, some species such as lionfish or water hyacinth may naturally disperse to or thrive in Maryland as water temperatures warm. In both cases risk assessments to determine potential impacts from these red alert species have not been performed, resulting in management uncertainty and an inability to inform the general public.

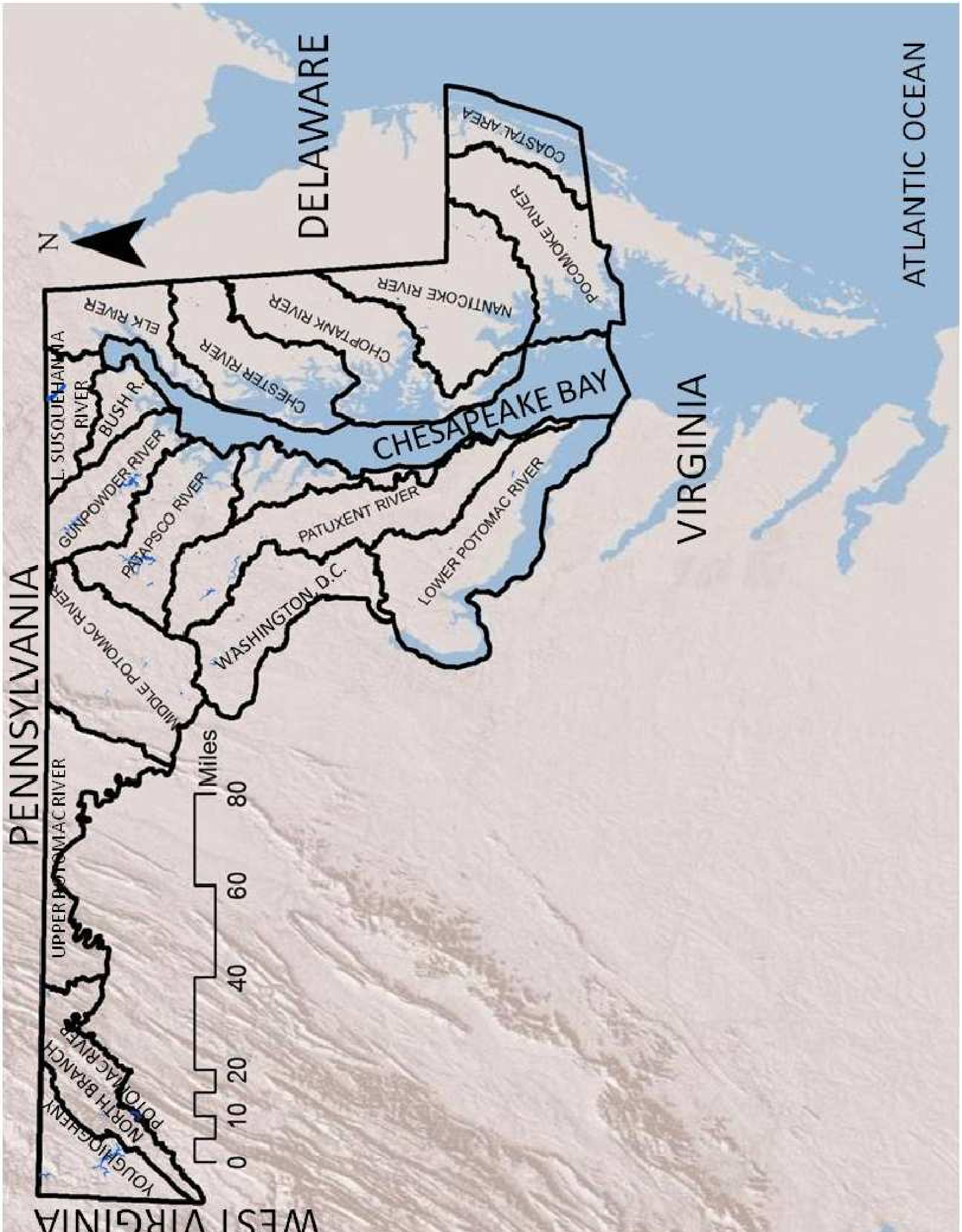

Figure 1. Map of Maryland with major basins and reservoirs.

PROBLEM DEFINITION

There are approximately 1051 non-native species reported in the United States Geological Survey's Nonindigenous Aquatic Species database (Fuller and Neilson 2015). Of those, about 10% are fishes (Pimentel 2005). In the Chesapeake Bay watershed, there are 120 introduced aquatic species listed by USGS (2014). Some species are cryptogenic with an unknown origin, such as Brown Pelican that was found in Maryland in 1981 either resulting from natural range expansion or introduction. For the purpose of this ANSP, only species that are known to be introduced from outside of Maryland will be prioritized as possible ANS. The probability that a non-native, introduced species' population will grow and expand its distribution depends on both the environment and natural history of the organism (Sakai et al. 2001; Kolar and Lodge 2002; Lapointe et al. 2013). The establishment of introduced ANS requires suitable habitat (Shafland and Pestrak 1982) and may be promoted through factors such as high propagule pressure or loss of native biodiversity (Levine 2000; Duggan et al. 2006), simultaneous introduction of pathogens that affect native species (Reynolds 2013), or climate change (Rahel and Olden 2008). Introductions are considered the reason for homogenization of North American fish communities (Rahel 2000) and the primary cause of changes in biodiversity in many aquatic ecosystems (Sala et al. 2000).

The intentional introduction of non-native species is an old and worldwide practice dating back at least 1000 years when carp were widely introduced throughout Eurasia (Moyle 1986). The stocking of sport fishes throughout United States in the late 1800's led to the establishment of nationwide fisheries for largemouth bass and have provided a stable source of food for the general public. In Louisiana, 2.5 million Florida bass (*Micropterus salmoides floridanus*) may be introduced to help promote sportfishing (ABA 2014). Unfortunately, very few of these authorized introductions have had formalized risk assessments, which led to unforeseeable problems (e.g., introduction of whirling disease, Modin 1998; escape of aquaculture species, Kumar 2000; gene introgression and hybridization, Dakin et al. 2015). The unauthorized or unintentional introduction of a species may be observed serendipitously, after populations have already established; though recent environmental DNA (or eDNA) techniques may help identify occurrences without direct observation (Jerde et al. 2011).

Not all species that have been introduced to Chesapeake Bay watershed are ANS (Christmas et al. 1998). Many non-native organisms may have beneficial or neutral impacts (Shafland 1996; Gozlan 2008). Those that are ANS have potential to cause or have caused negative economic and/or ecologic impacts. Some major ways ANS impact other species is through competition or predation. Competition and predation with ANS affects approximately half (53%) of the threatened or endangered fishes listed by the Endangered Species Act (Wilcove et al. 1998). Extinction as a result of competition with ANS is much less likely than extinction because of predation or habitat loss (Davis 2003).

Aquatic nuisance species may also: 1) reduce biodiversity and simplify aquatic food webs (Tyus and Saunders 2000; Ricciardi 2005; Vitule et al. 2009); 2) dramatically change primary productivity in aquatic habitats (Nicholls et al. 1999); 3) affect water clarity; 4) spread disease (Radonski et al. 1984; Hill 2011); 5) deteriorate gene pools for fishes (Philipp et al. 1983; Philipp et al. 2002; Laikre et al. 2010); and 6) increase operating costs (e.g. decontamination, gear replacement) for industry, boaters and anglers.

The negative impacts or costs and positive impacts of species introductions are often considered when reaching a consensus on the urgency to address ANS. For example, *Hydrilla* is a non-native ANS plant that negatively affects boaters (Pimentel et al. 2005) and waterfront homeowners, but has been credited for providing habitat for fishes (Kraus and Jones 2011) immediately following an unprecedented decline in native Chesapeake Bay grasses because of storms and poor water clarity (Orth and Moore 1983). Consequently, the level of control for *Hydrilla* can be debated between anglers and recreational boaters. The release of sport fish or game fish can be similarly contentious because of the potential to lower genetic fitness of the wild population (Hill 2011), to introduce disease (Bartholomew and Reno 2002), or negatively affect the food web (Jackson 2002). Pimentel et al. (2005) reported revenue of $69 billion per year in the United States because of introduced sport fish, but a conservative loss of $5.4 billion per year to mitigate negative effects of aquatic nuisance species in aquatic ecosystems.

Predictive models have been developed to determine whether a non-native species is likely to become ANS and negatively impact the ecosystem (Moyle and Light 1996; Kolar and Lodge 2002; Lodge et al. 2006; Hardin and Hill 2012). Quantitative and qualitative risk assessment tools have been developed to help predict consequences of introduction (e.g., McCann 1984; Kohler and Stanley 1984; Kolar and Lodge 2002; Vander Zanden and Olden 2008; Hardin and Hill 2012; Verbrugge et al. 2012). The use of these tools may inform governments and resource agencies on possible negative consequences of introduction from authorized pathways into regional waters (by State or Federal governments). However, they do little to prevent the introduction of species through unauthorized pathways, such as bait or aquarist releases or escapes from aquaculture. Once an ANS is established, the options for actions are often limited to slowing its spread and controlling its biomass.

A growing number of non-native aquatic plant and animal species have adversely impacted the productivity and biodiversity of Maryland's native species and altered a variety of aquatic ecosystems. Thick patches of *Hydrilla* can create patchy stagnancy in tidal freshwater habitats, which can exclude hypoxia intolerant fishes and macroinvertebrates from otherwise valuable habitat refugia. The widespread distribution of blue catfish and northern snakehead have altered food webs, leading to the consumption of prey that are then unavailable for other predators. The introduction of largemouth bass may have led to the decline or extirpation of black banded sunfish (*Ennacanthus chaetodon*) in some impounded waters. Several invasive crayfishes have been linked to dramatic declines in native crayfishes in many Maryland watersheds. In addition to loss in native biodiversity, ANS have the potential to simplify aquatic food webs, alter nutrient cycling, decrease habitat value or water quality, impair angler experiences, create increases in safety concerns for swimmers or boaters, decrease property values, and negatively impact industrial infrastructure (e.g., water intakes) or power generation.

HIGH PRIORITY PATHWAYS AND AQUATIC NUISANCE SPECIES

Vectors and Priority Pathways of Introduction

The following is a list of the vectors and associated pathways that are most responsible for non-native species introductions including ANS in Maryland. These pathways are the known, prioritized pathways in Maryland. Other pathways may exist, but these were prioritized by the authors because they are known or suspected pathways of introduction for aquatic organisms in Maryland waters.

Included in the following list is information on the known species that have been introduced via each vector and a description of the current state of knowledge of the vector, including gaps that currently hinder vector management and ANS prevention. Although this list captures most of the vectors that have historically played a role in ANS introductions and will likely continue to do so in the near future, this list is not comprehensive. New vectors and pathways emerge with increasing global trade and human population (Carlton and Ruiz 2005).

Maritime Commerce Vector

Ballast Water Pathway— Oceangoing ships utilize water as ballast to provide balance and stability from port to port. Prior to a given voyage, ballast water is pumped into large, onboard holding tanks in the area of a departure port. Organisms including algae, pathogens, a variety of invertebrates, and fish can also be pumped into ballast tanks from the surrounding environment during this filling process. Ballast water, and associated aquatic organisms, are often stored in these tanks throughout the entire voyage and then released at the port of call under the authority of the captain.

Discharge of ballast water from ships can often introduce non-native, ANS from distant continents to the receiving waters. However, the potential spread of ANS via ballast water discharge is not limited to transoceanic shipping. Intra-oceanic shipping can also lead to the spread of coastal marine organisms especially among ports with similar environmental conditions. Ballast water discharge has been responsible for establishment of over a third of marine ANS worldwide (Hewitt and Campbell 2010) and approximately 70% of ANS to the Great Lakes (Holeck et al. 2004) including zebra mussel (*Dreissena polymorpha*).

Suspected ballast water introductions have also occurred in the Chesapeake Bay. The veined rapa welk (*Rapana venosa*) a predatory snail from Southeast Asia, is a suspected ballast water introduction first reported in the Bay in 1998. It is currently established in Virginia waters, but is not known to occur in Maryland's portion of the Chesapeake Bay. An oyster disease called MSX is caused by a protozoan (*Haplosporidium nelsoni*) native to Japan and Korea and was likely introduced via the ballast water pathway, although other pathways may have been involved. It was first documented in the Chesapeake Bay in 1959. This ANS has caused high mortality in the eastern oyster (*Crassostrea virginica*) and has been one of several factors hindering oyster recovery efforts. Ballast water is also the suspected pathway responsible for the introduction of the Chinese mitten crab (*Eriocheir sinensis*), a catadromous ANS from eastern Asia. This species has been reported from estuaries along the Mid-Atlantic from Maryland to New York. It was first reported from the Patapsco River in 2005. There have been a total of four crabs collected in Maryland waters since 2005, but none reported since 2007. It remains unclear if this species is currently established in the state.

In recent years, management of the ballast water pathway has involved the establishment of international and national regulations and standards aimed at reducing ANS invasions. In 2004, the International Maritime Organization (IMO) established guidelines for ballast water exchange and a ballast water discharge standard. In 2008, the USEPA finalized the Vessel General Permit which required that all vessels entering United States waters conduct saltwater exchange or meet acceptable discharge requirements and that all inter-coastal vessels conduct mandatory ballast water management practices. The USCG also regulates ballast water discharge in United States waters under the United States. Final Ballast Water Rule adopted in 2012. This rule established specific discharge standards (similar to the international standard set by the IMO) and concentration limits on microorganisms. In Maryland's Chesapeake Bay, the regulatory authority and management of ballast water falls primarily under the jurisdiction of the United States Coast Guard.

While the ballast water pathway of the Maritime Commerce Vector is regulated, the Port of Baltimore ranks as the 13th largest port in the United States and third largest in the Mid-Atlantic behind Norfolk and New York in total tons of cargo imported and exported annually (MPA 2014). Maritime commerce at the port is likely to increase in coming years, possibly resulting in greater influence of the ship biofouling pathway. Recent widening of the Panama Canal will now allow Super Post-Panamax cargo ships to access East Coast ports. Baltimore is currently one of only a few such ports that have the cranes and other infrastructure to receive these large ships, which had been previously limited by their large size to the Pacific Coast.

Ship Biofouling Pathway—The accumulation of algae, plants, microorganisms, barnacles, mollusks, sponges, hydroids, tubeworms, tunicates, and other invertebrates on the superstructure of oceangoing vessels represents a significant pathway of ANS associated with the maritime commerce vector. As is the case with ballast water, biofouling organisms attached to hulls, propellers, and other ship surfaces can be transported from port to port and introduced into receiving waters.

Biofouling is the likely pathway responsible for 70% of ANS introductions in the coastal waters of North America (Fofonoff et al. 2003). Biofouling is the suspected pathway responsible for the initial introduction of the green crab (*Carcinus maenas*) on the East Coast of the United States. This ANS is now established in Maryland's Coastal Bay estuaries.

The ANS invasions resulting in dramatic changes in the function and integrity of aquatic ecosystems, declines in fisheries, human health concerns, and economic impacts associated with industry and infrastructure has prompted considerable international research on this vector since the 1980s (Davidson and Simkanin 2012). Ballast water and biofouling are among the most studied of ANS pathways and there is considerable ongoing research on ballast water treatment and antifouling systems. Management of biofouling has focused on anti-fouling paints or hull treatments to prevent the attachment of encrusting organisms.

Trade of Live Organisms Vector

Live Bait Pathway—The importation or harvest, distribution, use, and release of live bait comprise a significant pathway through which non-native potentially ANS species can be introduced and spread. Live bait introductions most often result from the release of unused bait by anglers and at the end of a fishing trip. These releases have been reported throughout much of the United States Anglers often view the practice of releasing unused bait as humane or beneficial to predatory game fishes (as prey) and the recipient ecosystem (Litvak and Mandrak 1993; Kilian et al. 2012). Regardless of the intent, releasing bait has been responsible for the introduction and spread of non-native earthworms, many species of fishes, crayfishes, and other invertebrates. Concern over introducing pathogens when using nuclear worms to fish inland waters in Maryland led to consideration of an import ban (AP 2005). Bait bucket introductions of ANS have been linked to altered chemical, physical, and biological processes within aquatic ecosystems and to declines and extirpations of native species (Moyle 1976; Hobbs et al. 1989; Goodchild 2000). The threat posed by this pathway is not limited to the bait species alone. Hitchhiking species including snails, worms, algae, and other invertebrates can also be introduced via the dumping of unused bait and its associated packing material (Haska et al. 2012). Hitchhiking parasites and pathogens, such as viral hemorrhagic septicemia, a disease that has caused large fish kills in the Great Lakes region, can also be harbored on or in contaminated bait.

Release of bait by anglers is the likely pathway responsible for introductions of four non-native crayfishes including three ANS: rusty crayfish (*Oroconectes rusticus*), virile crayfish (*O. virilis*), and red swamp crawfish (*Procambarus clarkii*) in some areas of the state. Red swamp crawfish was also introduced via aquaculture (see below). Bait introductions have also led to established populations of at least seven non-native fishes and this pathway is one of several sources of earthworm species to Maryland (Kilian et al. 2012).

To date, management of this pathway has focused mostly on the angler. It is illegal to release live bait into Maryland waters. There are also regulations that prohibit the use of certain bait types to reduce the spread of ANS. For example, anglers are prohibited from the use of live crayfish as bait in the lower Susquehanna River, Middle Potomac River, Monocacy River, and upper Potomac River. It is also unlawful to release live bait of any kind in Maryland waters. Regulations targeting wholesale and retail distributors prohibit the import, sale, and possession of certain ANS common in the live bait trade.

Aquarium/Pet Pathway—The live trade in aquatic organisms for aquarium hobbyists and pet owners is a 25 billion dollar-per-year and growing industry (Padilla and Williams 2004) that is responsible for the movement of thousands of species of animals and plants from around the world, many of which are non-native to the United States and some are potential ANS (Strecker et al. 2011). Introductions of non-native species including ANS associated with the aquarium/pet pathway occur primarily through the intentional release of unwanted organisms by pet owners and aquarists. The organisms can be purchased from on-line sources (e.g., craigslist, www.craigslist.com), commercial suppliers (e.g., Petsmart), or other aquarium hobbyists. This pathway is responsible for hundreds of introductions nationwide and is considered one of the top five overall pathways responsible for ANS introductions (Ruiz et al. 1997). A third of the world's worst ANS (as designated by the International Union for the Conservation of Nature) were introduced via the aquarium/pet pathway (Padilla and Williams 2004). As with the live bait pathway, hitchhiking organisms including pathogens and parasites also pose a threat to recipient ecosystems when released with their associated pet species.

In Maryland, introductions of aquatic pets have been routinely discovered in Maryland waters and include: pacu (*Piaractus* spp.), plecostomus (catfishes of the family Loricariidae), and peacock bass (*Cichla ocellaris*). These tropical species have low potential for establishing populations in Maryland. Other released species have become established and include: goldfish (*Carassius auratus*); red-eared (*Trachemys scripta elegans*) and yellow-bellied (*T. scripta scripta*) sliders; false map turtle (*Graptemys pseudogeographica*); and the Chinese mystery snail (*Bellamya chinensis*). There are hundreds of places to buy aquatic pets in Maryland.

Efforts to prevent ANS introductions via this pathway have focused on regulations restricting the import and sale of certain ANS (e.g., marbled crayfish) and on education/outreach to pet owners.

Water Gardening Pathway—Import and sale of live aquatic organisms for stocking outdoor water gardens is popular among hobbyists and a growing potential pathway of ANS. Introductions associated with water gardening usually occur through escape during floods or by wind and wildlife, or by improper disposal of ANS-contaminated material or water. This pathway is a significant source of known ANS as well as hitchhiking species 9of fungi, algae, snails, and other invertebrates (Maki and Galatowitsch 2004).

The water gardening industry is the suspected route by which *Hydrilla vetriculata* was first brought to Maryland and the Mid-Atlantic region. The original introduction of this ANS plant in the Potomac River subsequently occurred via the research and assessment vector (Fincham 2009) when National Park Service experimented with the species as a possible substitute for native grasses that had largely died in the Potomac River. Water gardening is also the likely pathway responsible for the introduction of water lettuce (*Pistia stratiotes*) to Mattawoman Creek in 2007. There were 5 known Maryland water gardening businesses identified in Maryland in a Google search in December 2015.

As with the aquarium/pet pathway, efforts to prevent ANS introductions via this pathway have focused on regulations restricting the import and sale of certain ANS and on education/outreach.

Live Seafood Pathway—The global seafood trade involves the importation and distribution of live aquatic species originating from distant locations and is a potential pathway of ANS (Chapman et al. 2003). The mechanisms of introduction associated with this pathway include the purchase of a species from a live seafood market or other vendor and the intentional release of fish and other organisms by consumers. Intentional introductions of live fishes, crabs, crayfish, and other seafood species may also result in the spread of associated hitchhiking species, parasites, and pathogens into recipient waters.

In Maryland, the import and release of live seafood is the likely source of introductions of the oriental weatherfish (*Misgurnus anguillicaudatus*) in the Patapsco River and the Asian swamp eel (*Monopterus albus*) in Lake Needwood in the Rockville, MD. Although multiple individuals of these two ANS have been captured in recent years, it remains unclear if these species are established. This pathway may have also been the source of introductions of northern snakeheads (*Channa argus*) into Potomac River and the Chinese mitten crab in Maryland and elsewhere in the Mid-Atlantic region.

There are federal and Maryland regulations that prohibit the live import or possession of some species, such as snakeheads. Regulations in Maryland also prohibit import, transport, purchase, live possession, propagation, sale or release of Asian swamp eel.

Biological Supply Pathway—Biological supply companies offer a variety of live organisms marketed for educational purposes. Many non-native aquatic plants, fishes, mollusks, crustaceans, and other invertebrates can be purchased from the world wide web. Online biological supply companies are a common source of live organisms used as teaching tools by science teachers. Introductions associated with this pathway usually occur because teachers and/or students release the organisms at the completion of their science lesson. A survey of teachers in the United States and Canada by Chan et al. (2012) found that one in four science teachers who used live organisms in their classrooms also released them into the wild. The biological supply pathway has been implicated in the introductions of three crayfishes that are ANS in the Pacific Northwest (Larson and Olden 2008, 2011). Many species purchased through biological supply companies are ANS and shipments are often contaminated with other non-native organisms.

The MDDNR has received numerous anecdotal reports of teachers releasing live aquatic species purchased from online vendors into Maryland waters. In response, MDDNR has focused education/outreach to inform teachers and school science departments to minimize this practice.

Water Recreation Vector

Boating Gear Pathway—The use of small motor boats, sailboats, pontoons, jet skis, canoes, kayaks, and other watercraft is an increasingly common pathway associated with the spread of ANS in inland waters. Introductions associated with this pathway arise when non-native, potential ANS are inadvertently carried between water bodies in bilge water, engine cooling systems, live wells, or attached/ entangled to hulls, trailers, or other surfaces. Because recreational boats and associated gear can be transported by trailers over great distances, the use of contaminated watercraft can be a source of new ANS to Maryland. Recreational boating can also serve as a secondary pathway through which ANS originally introduced via other vectors are transferred between nearby water bodies (Kerr et al. 2005). This pathway is believed to be responsible for the spread of problematic plants (e.g., Eurasian watermilfoil, *Myriophyllum spicatum*) and animals (e.g., spiny waterflea, *Bythotrephes longimanus*). It is the most important pathway responsible for the spread of zebra mussels from the Great Lakes throughout the United States.

Maryland's coastal estuaries, Chesapeake Bay, and many large inland reservoirs are popular tourist destinations among recreational boaters, kayakers, and canoeists. Many boaters using these waters come from adjacent states. Some boaters on Maryland waters trailer their watercraft from as far west as Utah (MDDNR, Mark Lewandowski, Deep Creek Boat Inspection, 2014), which emphasizes the large geographic scope of this potential pathway. Recreational boating is the likely pathway responsible for the introduction of *Hydrilla* and Eurasian watermilfoil in Deep Creek Lake.

This pathway is regulated in Maryland by House Bill 860 that stipulates boaters must remove organic material from boats before launching in state owned impounded waters. Education/outreach efforts have also encouraged boaters to follow best management practices to minimize the spread of ANS via boating.

Angling Gear Pathway—Anglers can inadvertently transport and introduce ANS that become attached to or contained within unclean equipment including fishing rods, tackle, waders, wading boots, and other angling gear. This is one of the suspected pathways responsible for introductions of New Zealand mud snail (*Potamopyrgus antipodarum*) and spiny waterflea in many United States waters. It is also the suspected pathway by which the invasive alga didymo (*Didymosphenia geminata*) was introduced into coldwater trout streams in many countries and throughout much of the United States, including Maryland (Bothwell et al. 2009). Pathogens such as whirling disease can also be transported between water bodies on contaminated fishing gear.

In response to the introduction of didymo, the MDDNR banned the use of felt sole waders or wading boots in Maryland waters to minimize the potential transport of this and other ANS. The MDDNR and partners also established wader washing stations at many popular fishing locations.

SCUBA Gear pathway—Regulators, buoyancy control devices, weight belts, wetsuits, and other gear used by recreational and commercial divers can, when not properly dried or decontaminated, serve as vehicles on which ANS can be transported between water bodies. This is the suspected pathway responsible for the introduction of zebra mussels in Millbrook Quarry (VA), which is an abandoned stone quarry used for dive training (Fernald and Watson 2005). This recreational activity is common in Chesapeake Bay watershed and on Maryland's Atlantic Coast.

Stocking Vector

Authorized Stocking Pathway—Authorized fish stocking by government agencies has long been a means by which species have been introduced outside of their native ranges to create fisheries for anglers. Fish stocking has been largely successful in enhancing the variety and numbers of game fishes available to anglers throughout the United States. There are many examples, however, where authorized introductions have also led to negative ecological impacts (Fuller 2003). For example, blue catfish (*Ictalurus furcatus*) ~~and flathead catfish (*Pylodictis olivaris*) were~~was introduced for sport fishing in ~~the Potomac River in the 1960s~~tidal rivers of Chesapeake Bay watershed by Virginia Department of Game and Inland Fisheries. Largemouth bass (*Micropterus salmoides*) was intentionally introduced to Maryland shortly after the Civil War to provide local people a year-round food source. Common carp (*Cyprinus carpio*) was also introduced as a food species throughout much of North America (Fuller 2003) and is now widespread in Maryland waters. Authorized stocking of species to support a prey base for sport or game fishes is also a pathway that has been responsible for the introductions of several non-native fishes in Maryland, including threadfin shad (*Dorosoma petenense*) and emerald shiner (*Notropis atherinoides*). Legal stocking for the purpose of biocontrol is also a common source of non-native, potential ANS. Grass carp (*Ctenopharyngodon idella*) and western mosquitofish (*Gambusia affinis*) are ANS that have been stocked in many United States waters for control of aquatic vegetation and mosquitoes, respectively.

Negative impacts from authorized stocking has included depredation of native organisms by top predators, loss of water clarity because of grazing by carp, and introduction of hitchhiking non-target organisms (e.g., crayfishes, snails).

Risk assessment methods and internal review of proposed stockings should prevent future introductions of ANS associated with the authorized stocking pathway.

Unauthorized Stocking Pathway—Unauthorized stocking for the purposes of developing a sport fishery, forage base, harvest fishery or biocontrol can result in introductions and spread of ANS and non-target, hitchhiking organisms and pathogens. Unauthorized movement and release of blue catfish by the general public has likely hastened the spread of this species throughout Chesapeake Bay watershed. This practice has also led to introduction of Northern Snakehead to ponds in Crofton (MD), the Potomac River and the Nanticoke River.

The MDDNR Fisheries Service has regulatory authority over fish stocking in Maryland waters. Authorized stocking of private ponds requires a permit issued by MDDNR. This process involves the review of the species and sources of those species planned for stocking. However, not all members of the general public seek a permit and unauthorized introductions occur.

Management of unauthorized stocking includes a combination of regulation and education. Research is needed to better understand motives behind illegal transport and introduction of game species (e.g., blue catfish, northern snakehead) and to identify communication and outreach techniques that both highlight existing laws and convince the general public to avoid releasing species without first obtaining a permit.

Religious Release of Wildlife Pathway—Ceremonial animal release, a traditional ritual in Buddhism and other Asian religions, is the practice of releasing captive wildlife including turtles, frogs, and fishes for religious purposes (Shiu and Stokes 2009; Liu et al. 2013). This ritual, practiced among religious groups in the United States and Canada, has been linked to the spread of ANS (Shiu and Stokes 2009). This practice can involve the release of large numbers of organisms in a single event, and can be performed frequently among some Buddhist groups (Shiu and Stokes 2009). This vector is a possible pathway by which northern snakehead (*Channa argus*) was first introduced to the Potomac River drainage near Washington, DC.

Aquaculture Vector

Aquaculture Pathway—The importation of aquatic organisms for the purpose of aquaculture is a major vector responsible for introductions of ANS (Naylor et al. 2001) because of escape of cultured organisms from aquaculture facilities through outflow pipes or during flooding events. Bighead carp (*Hypophthalmichthys nobilis*), silver carp (*H. molitrix*), and black carp (*Mylopharyngodon piceus*), three ANS native to Asia were originally imported to the United States for aquaculture. These species subsequently escaped aquaculture facilities and are now established throughout much of the Greater Mississippi River drainage (Fuller 2003).

This vector has played a significant role in the introduction of ANS in Maryland. Aquaculture is the known vector for the introduction of two non-native crayfishes including the southern white river crawfish (*P. zonangulus*) and the red swamp crawfish. These species, originally introduced to outdoor farm ponds for culture as food, subsequently invaded nearby streams and rivers and are firmly established in many Maryland watersheds (Kilian et al. 2009). Introductions arising from aquaculture escapes have resulted in significant biological impacts (Grosholz et al. 2015).

The MDDNR Fisheries Service issues permits to aquaculture facilities in Maryland. As part of the permitting process, species proposed for aquaculture undergo review by MDDNR biologists to assess potential ecological risk and invasion potential. Even with this oversight, there is still considerable potential for the introduction of ANS as a result of contaminated source stocks and misidentifications of species used in aquaculture.

Canals/Dam Removal Vector

Canals/Dam Removal Pathway—The construction of canals in the late 1800's and early 1900's connected many river drainages which allowed for the free movement of aquatic organisms between systems that were previously separated by bio-geographical barriers (Fuller 2003). The construction of canals played a large role in the spread of sea lamprey (*Petromyzon marinus*) in the Great Lakes. Similarly, the Chicago Shipping and Sanitary Canal provided the corridor through which the round goby spread from the Great Lakes to the Upper Mississippi River drainage (Fuller 2003).

The Chesapeake and Ohio Canal parallels the Potomac River and can intermittently provide a low-gradient, slow water habitat through which ANS could traverse natural dispersal barriers like Great Falls on Potomac River. Several fishes, crayfishes, and amphibians native to the coastal plain of Maryland have utilized the C&O canal to expand their distributions westward across the Fall Line (Stranko et al. 2003; Kilian et al. 2010). This same corridor has also provided access to the non-tidal Potomac River by northern snakehead.

The removal of dams and the construction of fish ladders are common practices used in the restoration of diadromous fishes and riverine habitats. By restoring riverine connectivity, these techniques are often successful at providing access of migratory fishes to previously inaccessible habitats for spawning. However, dam removal and fish ladders can also provide free movement of ANS.

The extensive permitting procedure associated with development of canals or removal of dams should minimize the potential for ANS introductions and spread. Construction of canals, dam removal, and construction of fish ladders are authorized via Maryland Department of Environment, Army Corps of Engineers, other agencies, and reviewed by MDDNR Environmental Review Unit. The MDDNR, USFWS, and other organizations involved in dam removal and fish passage programs consider the potential dispersal of ANS when evaluating proposed dam removal and fish passage projects. The scrutiny associated with review of such stream altering projects allows consideration of range expansion by ANS. To prevent the movement of ANS through the existing or new canals in Maryland, monitoring of distribution and on-the-ground population control efforts are necessary.

Research and Monitoring Vector

Research and Monitoring Pathway—Aquatic research and monitoring involves various activities (e.g., bio-assessments, fish kill investigations, restoration projects, water quality assessment, and population/status surveys) that pose a risk of transporting and introducing ANS. Many of these activities entail the use of equipment such as boats and trailers, and other gear (e.g., waders, nets) on multiple water bodies in a given day and there is a high potential for ANS to hitchhike between waters attached to or contained within equipment and gear. Only a fifth of surveyed fisheries programs at colleges and universities reported having a protocol in place for preventing the spread of ANS (Westhoff and Kobermann 2015). Aquatic research can also involve *in situ* experimentation where ANS could be inadvertently introduced. In 1980, National Park Service scientists conducting research to restore aquatic vegetation to the Potomac River used *in situ* experimentation in Dyke Marsh near Washington, D.C. with what they believed to be a type of Elodea. Their experiment led to the first reported invasion of *Hydrilla* in the Mid-Atlantic region (Fincham 2009). Similarly, experimental introductions of the Asian oyster (*Crassostrea gigas*) by scientists working on oyster restoration is one of two suspected vectors responsible for the introduction of the disease MSX in Chesapeake Bay (Burreson et al. 2000). Research collection activities by non-MDDNR personnel are permitted by MDDNR, which provides the opportunity to encourage cleaning of equipment. Management of this pathway will require additional outreach to and compliance by researchers.

Knowledge Gaps and other Challenges Associated with Vector/Pathway Management:

The pathways of the Trade of Live Organism Vector are challenging without adequate regulation and education. In Maryland, retail bait shops frequently sell known and potential ANS and most bait sold in these shops is imported from wholesalers and sources out-of-state or the Mid-Atlantic region (Kilian et al. 2012). Unused bait (live fishes and crayfishes) was released by the majority of anglers in a survey of Marylanders (Kilian et al. 2012). Likewise, the large numbers of non-native aquatic species in the aquarium/pet trade and their subsequent introductions indicate that this pathway is an active route of potential ANS in Maryland. Identifying the species of highest concern within this vector may be complicated because of inconsistencies in the use of common and scientific names, misidentification and/or mislabeling of species in trade, and contamination of traded species with non-target hitchhikers (Maki and Galatowitsch 2004; Keller and Lodge 2007)

The pathways of the Water Recreation Vector require change in the behaviors of the tens of thousands of stakeholders (i.e., boaters, anglers, divers) involved in water recreation throughout the state. Encouraging stakeholders to actively and consistently decontaminate and/or dry their boats will require large scale outreach efforts, cooperation among state agencies and within agencies of Maryland.

Of the remaining vectors, stocking of animals as part of the Religious Release of Wildlife pathway may be problematic in the future. The extent and frequency to which ceremonial release occurs in Maryland is not well understood and deserves focused research. Management of this vector will require a better understanding of the ethical viewpoints of the stakeholders involved so that successful communication strategies (Liu et al. 2013) can be developed. Because releasing fish species to private ponds and other waterways in Maryland requires a stocking permit, communication with interfaith organizations is needed to ensure such permits have been obtained.

High Priority and Red Alert Aquatic Nuisance Species

The following sections provide ranks of high priority or red alert species for those that are considered ANS in Maryland. High priority ranks were assigned to established species or species groups for which there is a high probability of negative economic and/or ecological impact. Red alert ranks were assigned for species that are not established, have a high potential for introduction to Maryland either by natural range expansion or unauthorized introductions, and have a high probability of negative economic and/or ecological impact. High probability of negative economic and/or ecological impact was primarily determined by experiences within the Maryland ISMT as well as whether the species was listed as injurious by the United States Fish and Wildlife Service, whether there was a State or Federal adopted management plan for the species, or whether negative impacts were indicated by a preponderance of studies in Maryland or other jurisdictions. A rank of unknown was assigned to taxa that had little information allowing for a reasonable determination of potential economic or ecological impact. Some aquatic species that are introduced in Maryland waters do not constitute ANS and are ranked low priority. All known introduced aquatic species and assigned ranks are provided in Appendix 1.

High Priority Freshwater Animals and Control/Eradication Methods

Northern snakehead (*Channa argus*)—Native to Asia, yet has several populations in United States waters, including Maryland, Virginia, Delaware, and Washington, D.C. Since its listing as injurious wildlife under the Lacey Act, it has become illegal to possess a live snakehead in Maryland, Delaware, Virginia, and Washington, DC. While laws have likely helped reduce illegal introductions, the species has naturally spread beyond Potomac River and Nanticoke River, where it had been introduced. The species poses a threat to native fishes and crustaceans and competes with other top predators, such as largemouth bass (Saylor et al. 2012; Love and Newhard 2012). Extirpation of species has not been documented in areas invaded by snakeheads. Control efforts to prevent the spread of northern snakehead include encouraging harvest and engaging the public in a broader dialogue to reduce propagule pressure and the release of ANS. An ANSTF approved plan for control of snakeheads nationwide is available ~~for public comment~~ at:

http://www.anstaskforce.gov/control.php

Blue catfish (*Ictalurus furcatus*)—Native to some parts of North America, blue catfish were intentionally introduced into tidal waters of Virginia in the early 1970's ~~Potomac River in the 1960's~~ as a sport fish. Since then, the species has spread to tidal Potomac River and throughout Maryland's waterways through unauthorized introductions and naturally. Competition with native catfishes, and possibly predation by blue catfish on native catfishes, could lead to extirpation of native catfishes such as white catfish (*I. catus*) and bullheads (*Amerius* spp.). Blue catfish can grow to over 100 pounds and constitute a formidable predator capable of high levels of reproduction. Maryland currently has regulations to prevent release of live blue catfish from a different waterway than it was caught. There are also marketing campaigns aimed at reducing biomass of the species using harvest for human consumption and production of non-consumptive uses such as fertilizers.

Flathead catfish (*Pylodictus olivaris*)—Native to the Mississippi River drainage of North America, this species is now found in the Potomac River, the upper Chesapeake Bay, and the Elk and Sassafras Rivers. It was introduced to Occoquan Reservoir, Virginia, then spread to the Occoquan River, which is part of the Potomac River. There are individuals in the upper Potomac River, but origin of this fish introduction is unknown. The species spread from the Susquehanna River in Pennsylvania and into the upper Chesapeake Bay of Maryland. In suitable habitats, the species can quickly establish itself and amass large sizes (up to 1.4 m in length). The principal way the fish negatively impacts aquatic ecosystems is through predation. The species eats primarily fish and crustaceans. Because of predation, it can quickly decimate native catfish populations and possibly sport fish, such as sunfish (Thomas 1993).

Zebra mussel (*Dreissena polymorpha*)—Introduced with ship ballast water to North America in the 1980s, the zebra mussel has caused significant negative economic and ecological impacts to the Great Lakes region and other parts of the United States (Vitousek et al. 1996). It is a filter-feeding, small bivalve that can inhabit fresh and slightly brackish waters. The species was first documented in Maryland in November 2008 at Conowingo Dam on the lower Susquehanna River when a single dead adult was found in an American shad collection basket on the upstream side of the dam. Since then, additional zebra mussels have been collected on boat hulls and other substrates in the surrounding area as well as on intake structures at two drinking water facilities. There is currently an established population in the lower Susquehanna River, both upstream and downstream of Conowingo Dam. As of 2014, zebra mussels have been collected at two other locations in upper Chesapeake Bay: Elk Neck and in the Sassafras River. Because of the impacts documented in the Great Lakes and other invaded areas, its recent appearance in Maryland and possible spread to other water bodies warrant concern. In 2002, a workshop was held to develop species management strategies for some ANS, such as zebra mussel that had not been found in Maryland at the time (Moser 2002). One of the major strategies included outreach, but additional strategies may be necessary now that the species is established. A reporting system and more information on zebra mussel can be found at:

http://dnr2.maryland.gov/Invasives/Pages/zebra_mussels.aspx

Crayfishes—Non-native ANS in Maryland include virile crayfish (*Orconectes virilis*), rusty crayfish (*O. rusticus*), and red swamp crayfish (*Procambarus clarkii*). All three of these species have been linked to declines of native crayfishes in other regions where they have been introduced. These species currently represent the greatest threat to Maryland's native crayfish diversity. Virile crayfish, the most abundant and widespread ANS crayfish in Maryland, was first reported in the late 1950's from the Patapsco River. It is now found in 44 watersheds in Central and Western Maryland. Its spread has been followed by the concomitant, precipitous decline of the native spinycheek crayfish (*O. limosus*) and Allegheny crayfish (*O. obscurus*) in the region. These native crayfishes are now extirpated from many watersheds where virile crayfish is currently abundant. From extensive studies in other regions, these three ANS also have the capacity to adversely affect stream insects, mussels, snails, amphibians, reptiles, fishes, and sport fisheries and alter community structure and function. Aside from observed declines to native crayfishes, the impacts of these ANS on other aspects of Maryland's aquatic ecosystems are not well understood at this time, but deserve further study. Although several vectors and pathways including the pet trade, biological supply trade, and aquaculture have played a role in the introduction of crayfishes in Maryland, bait bucket introductions by anglers have been most responsible for the introduction and spread of these problematic species. Based on a survey of Maryland's freshwater anglers conducted by MDDNR in 2008, the release of live, unused bait is a common practice among Maryland anglers – especially among anglers who use live crayfish. Of those anglers who used live crayfish as bait, 69% reported releasing unused crayfish into Maryland waters (Kilian et al. 2012).

Whirling disease—Caused by a freshwater myxozoan (*Myxobolus cerebralis*), it was first described in rainbow trout (*Oncorhyncus mykiss*) in Europe, but was subsequently introduced to North America in the 1950's and Maryland in the 1990's. Whirling disease may have been introduced by anglers or by the introduction of an intermediate host into the North Branch of the Potomac River, from where the disease was introduced to an open water hatchery that grew trout. *Myxobolus cerebralis* has a complicated life cycle and requires an intermediate host; a tubicifid oliogochaete. Intermediate stage parasites released from these worms seek out very young trout. The bacteria destroy cartilage in the head and spine. Whirling disease is often fatal to juvenile fish by causing neurological damage or skeleton abnormalities. This damage causes the young trout to swim in circles, or "chase their tails", and may cause the tail to blacken as the spine is damaged. Once the damage is done, the parasite enters a final, resistant spore stage that is released once the fish dies and decomposes. The parasite was introduced to Maryland trout hatcheries from unknown sources and it found its way into a few isolated waters. Through careful management, the parasite has been eliminated from major trout production facilities. Routine screening is conducted yearly to confirm the absence of the parasite. The North Branch of Potomac River has two streams that continue to carry the parasite, yet it is unknown if whirling disease is impacting any young trout in these areas. Whirling disease is tested, monitored and is currently under control by MDDNR.

Mute swan (*Cygnus olor*)—An ANS of the Chesapeake Bay watershed introduced from Europe to the Atlantic coast in the late 1800's. In Maryland, the species was first observed near Ocean City in 1954. While the population was small for numerous years, after the 1980's population growth dramatically increased and resulted in a sizeable increase in range. The population increased dramatically between 1986 and 1999 because control methods were not initiated. When control methods were initiated (e.g., egg addling, removal of adult swans), the population declined quickly to at least 1% of its reference size. Negative impacts from mute swan have included: 1) foraging impacts by lowering the biomass of submerged aquatic vegetation; and 2) displacing state-threatened colonial water birds (e.g., terns). Mute swans have killed wetland birds and can be aggressive to humans. To date, efforts to reduce mute swan populations in Maryland have been largely successful. Actions to maintain low biomass of mute swan remain a high priority. A management plan to control the biomass of mute swan has been developed by the MDDNR appointed Mute Swan Task Force:

http://www.dnr.state.md.us/irc/docs/00014261.pdf

Resident Canada Goose (*Branta canadensis*)—Canada goose is common in Maryland and there are both migrants and residents. The migratory Canada goose overwinters in Maryland where it escapes the cold of Canada and Hudson Bay. Year-round residents occurred because of releases of the bird in 1935 to Dorchester County from the midwest. Both migrants and residents inhabit ponds, lakes, marshes and urban areas. It is legal to hunt Canada goose during fall in Maryland, but other controlled hunts and programs develop when a flock of Canada goose becomes over abundant. Large flocks may create hazards for waterways as goose poop nitrifies streams. Large birds may also be aggressive to humans.

Nutria (*Myocaster coypus*)—A prolific, aquatic rodent native to South America introduced into the United States in the early 20th century for fur farming and weed control. Individuals escaped or were intentionally released into Dorchester County in 1943, after which the population size increased to approximately 50,000 by the early 1990's. The species excavates plant roots, which leads to marsh erosion and wetland destruction. In 2002, eradication of the species from the eastern shore of Maryland began at an expense of $20 million over 5 years. The project has removed over 13,000 nutria from 150,000 acres in 5 eastern shore counties. As a result of the removals, the damaged marsh is recovering. Resulting actions from this plan have greatly reduced nutria numbers on the eastern shore of Maryland, yet the species still remains a threat. An interagency management plan by the Chesapeake Bay Nutria Working Group was developed in 2003:

http://www.fws.gov/chesapeakenutriaproject/PDFs/CNEP_strategic%20plan_3_2012.pdf

Red Alert Freshwater Animals and Control/Eradication Methods

Silver carp (*Hypophthalmichthys molitrix*) and **bighead carp** (*H. nobilis*)—Freshwater fish from Asia introduced to the Mississippi River basin in the 1970's to control algal growth in aquaculture. Individuals escaped from those facilities shortly after they were brought here from Asia. The species have widely spread throughout the Mississippi River and Ohio River basins in only 30 years. While the species have not yet been detected in Maryland, it is possible that they will arrive in Maryland through the Ohio River Basin. Dams have slowed their expansion on Mississippi River and dams and the uplift of the Appalachian Mountains may likewise, slow their spread into Maryland waters. The species causes a hazard to navigation because of their tendency to leap out of the water when startled. As fish leap from the water, boaters, jet skiers, and water skiers may be injured. The species may also negatively impact ecosystems by lowering abundance of native mussels, invertebrates, and fishes. Foraging by silver carp (*Hypophthalmichthys molitrix*), an ANS in the Mississippi River and Laurentian drainages (Chen et al. 2007), will severely deplete plankton resources in otherwise plankton-rich areas (Spataru and

Gophen 1985; Cooke and Hill 2010). Control programs to market the species commercially as food have been recently attempted, though it is not clear whether these markets will lower biomass of these carp species or not.

Asian swamp eel (*Monopterus albus*)—A fish from Asia that has been introduced through the commercial food fish trade or aquarium trade to Florida, Georgia, and Hawaii. In 2008 and 2012, the species was caught in Silver Lake (Gibbsboro, NJ) and the population is considered established. Because the species was collected incidentally from Lake Needwood in 2013 (MD) and the good likelihood of establishment in Maryland, this species may pose a threat to Maryland waters in the near future. The species is an opportunistic forager, but ecological impacts in North America are relatively unknown. The species could displace other aquatic species by competition or predation. Control measures have been implemented in Florida Everglades. These measures include a combination of electrical barriers, vegetation removal, and trapping. In Maryland, it is illegal to import, transport, purchase, possess, propagate, sell or release a live Asian swamp eel.

Round goby (*Neogobius melanostomus*)—An euryhaline species native to Europe which has become established in the Great Lakes. It was introduced by ballast water into the Great Lakes. The species has not been collected in Maryland. The fish may grow up to 25 cm, but is generally smaller (10 cm) and are mottled with tan coloration along the body, with a conspicuous melaophore on the distal end of the spiny dorsal fin. It consumes benthic organisms, such as worms and zebra mussels. It is considered an aggressive competitor that may outcompete native benthic fishes for prey or nesting habitats. Because it also consumes zebra mussel, the species may benefit the Great Lakes region by helping to lower abundances of zebra mussel.

New Zealand Mud Snail (*Potamopyrgus antipodarum*)—A small, 4 - 6 mm length euryhaline (< 15 ppt) mollusk with an elongated shell with 7 - 8 whorls separated by deep grooves (Costil et al. 2001; Gérard et al. 2003). The species is native to lakes of New Zealand but has been introduced to the Great Lakes of North America because of ballast water releases and several waterways of western United States because of contaminated waters shipped with game fish. In North America, the species was first discovered in Snake River (Idaho) in 1987. It then spread throughout the western United States. In 1991, the species was also discovered in Lake Erie, from which it spread to neighboring Great Lakes. The species has not yet been collected in Maryland. The animal grazes on plant and animal detritus as well as periphytic algae. It is also ovivivparous and parthenogenic, which likely contributed to its rapid range expansion once introduced. Its range expansion may also be owed to transport by fishes that ingest the snail and pass it alive through its anus. The species can also be spread inadvertently by anglers and boaters on contaminated gear. The species may alter primary production of streams and spread rapidly (EPA 2008). Control methods have included chemical treatment of water bodies and introduction of parasites from New Zealand. Preventing introduction has included methods aimed at boat and equipment decontamination.

Feral swine (*Sus scrofa*)—Wild boar has been introduced worldwide and originated from Europe and Asia. It is found on every continent except Antarctica. In Maryland, free-ranging pigs have been documented but never found reproducing. Wild or feral swine destroy crops, degrade natural ecosystems, spread disease, and attack people and pets (pers. comm., J. McKnight, Chair of Invasive Species Matrix Team, MDDNR). The spread of feral swine from southern states into Maryland may occur naturally. When feral swine are found and it is not a domestic pig, then it is encouraged for hunters to kill it and contact MDDNR.

High Priority Freshwater Plants/Algae and Control/Eradication Methods

Waterwheel (*Aldrovanda vesiculosa*)—A small carnivorous plant native to Europe, Asia, Africa and Australia, waterwheel has whorls of small leaves that help trap small arthropods and insect larvae. The species has gone extinct throughout much of its native range and only 50 known locations still have viable populations (Cross 2012). It is cultivated for sale in vendors. It has been found in New Jersey, New York, coastal Virginia and Maryland. In Maryland the species has been found in Prince Georges County, but it is not common. The species can be spread by movement of waterfowl and plants sticking to the feet of birds. It can also be spread by water flow and flooding.

Didymo (*Didymosphenia geminata*)—This species is a freshwater diatom that uses stalks to attach to streambed material. Native to Canadian cool water streams, didymo has been reported in the United States for over 100 years; however, blooms are occurring now with increasing frequency and intensity, and was first discovered in Maryland tributaries of Gunpowder River in 2008. The diatom was discovered in Savage River in 2009, the North Branch of Potomac River in 2011, and Big Hunting Creek in 2012. Didymo can form massive blooms that smother streambeds and adversely affect freshwater fish, plant, and invertebrate species by depriving them of habitat. Blooms may also impact recreational opportunities. This species formed blooms in fast-flowing, cold, nutrient-limited waters. After its discovery, MDDNR took action to educate the public and to prevent spread by installing wader wash stations to encourage anglers to clean their waders free of didymo. In 2011, MDDNR implemented a policy to ban felt-soled waders to help curb spread of didymo.

Brazilian elodea (*Egeria densa*)—This species was likely released from the aquarium trade. The species is native to South America and was originally imported to the United States for the aquarium trade. It may have spread in Maryland by boaters or spread naturally through fragmentation. The species can form thick and dense mats of vegetation that outcompete native aquatic plants. The mats often interfere with swimming, boating, fishing, or other recreational uses of waterbodies. Control of Brazilian elodea has been performed by mechanical and chemical means as well as biological control by triploid grass carp.

Hydrilla (*Hydrilla verticillata*)—This species is a waterweed that is native to Asia, Europe, Africa, and Australia. A common aquarium plant, it was first introduced to Florida in 1960s and is established in many areas of the United States It is possible that

Hydrilla was introduced to Maryland from the aquarium trade. The species became abundant in Potomac River in the 1980s following massive losses of submerged vegetation following Hurricane Agnes. Stems grow up to 1 – 2 m and leaves are arranged in whorls. The species has a high tolerance to salinity and reproduces by fragmentation and rhizomes. The density of *Hydrilla* causes problems for boat traffic and for recreational angling. Control of the plant using herbicides in Deep Creek Lake cost Maryland approximately $205,000 in 2014. Herbicides are most commonly used by MDDNR to control the biomass of the species in impoundments and ponds. In tidal rivers and impoundments, mechanical harvesters have been used; but this technique has been discontinued as it is expensive and labor intensive.

Purple loosestrife (*Lythum salicaria*)—This species is a wetland plant from Europe and Asia. It was transported into North America in the 1800's as seeds and plant parts by ballast water of sailing ships. After its initial introduction, the plant spread naturally among canals and ditches as well as intentionally as European colonists transplanted the species believing it could be used for medicinal healing. The species competes with many native wetland plants and forms dense stands that reduce food or nesting sites for native species. The MDDNR began a biological and chemical control program in 2007 with State Highway Administration (SHA) and Maryland Department of Agriculture (MDA) to eradicate purple loosestrife. Using citizens as scouts for locations of the plants, MDA raised and released beetles as a biocontrol agents. Biological controls have been used in addition to hand-pulling and chemical treatments. Of these, chemical treatment was considered highly effective. Currently, Maryland has only a few stands of purple loosestrife. The general public can report purple loosestrife stands at:

http://dnrweb.dnr.state.md.us/wildlife/PurpleLoosestrife/plrform.asp

Marsh dayflower (*Murdannia keisak*)—Native to temperate and tropical parts of Asia, marshy dayflower was accidentally introduced into the United States in South Carolina around 1935. It is an annual, emergent plant that invades wetlands and forms dense mats that out-compete native vegetation. It was first reported in Maryland in 1971 from the Eastern Shore and has since become well-established in coastal areas. It is found in freshwater marshes, pond edges, ditches, streams and will likely spread into every county in Maryland over time (pers. comm. Wesley Knapp, MDDNR). Control includes hand pulling and root removal to ensure depletion of the seed source. The species readily reproduces from vegetative fragments and can spread with mechanical removal.

Parrot feather (*Myriophyllum aquaticum*)—Native to South America, it is a popular plant for aquatic gardens in the United States because of its attractiveness. Once introduced, the species aggressively colonizes and dominates lakes, ponds, and ditches because of its ability to spread readily through fragmentation. In water bodies where the species dominates, the plant can entirely cover the surface and make it difficult for boaters, swimmers, or anglers to utilize the waterway. Control methods are often expensive and include mechanical removal.

Eurasian milfoil (*Myriophyllum spicatum*)—Native to Europe and Asia, this species was commonly sold as an aquarium plant in the United States. It is now found throughout much of the Nation and has been established in several eastern states since at least the 1940s. It is abundant in many Maryland waterbodies and continues to spread by boat trailers and human transport. The species forms dense mats that can negatively affect the waterbody as well as swimming, fishing, and other recreational activities. Clogging caused by the mats may also interfere with power generation and irrigation. The species begins growing in spring early, which gives milfoil a competitive advantage and can shade out or suppress growth of native plants. Milfoil reproduces quickly through seeds and fragmentation and can infest an entire lake within 2 years of introduction. Once established, the species is difficult or impossible to eradicate. Control methods have included herbicides, underwater rototilling, hand pulling and triploid grass carp.

Common reed (*Phragmites australis*)—This species is a wetland plant found throughout the United States and Maryland's wetland habitats. Both native and introduced genotypes of this species currently exist in North America. The origin of the species is unclear and it natively occurs in many areas of North America. The non-native genotypes may have been introduced in ballast material in late 1700's or early 1800's from Europe. The species is long-lived and can grow up to 6 m high. It can reproduce by seed, but more often reproduces asexually by rhizomes. The species can form dense, monotypic stands that utilizes resources; thus excluding other plant species. Control methods have included herbicide, hand-pulling, and burning. A draft management plan was developed for common reed (Moser 2002) and a best management practices document for managers and the public was suggested. More information on controlling *Phragmites* is found at:

http://dnr2.maryland.gov/wildlife/Pages/plants_wildlife/Phragmites.aspx

Water chestnut (*Trapa natans*)—First observed near Concord, Massachusetts in 1859, this species has since become established in many states, including Maryland. It was first discovered in Maryland in Potomac River in 1923. The pathway of introduction is unknown. It is prohibited from sale in most southern states. Once established, the species forms dense floating mats that limit light and reduce dissolved oxygen levels. Its fruits have sharp spines that can cause painful puncture wounds when stepped on, even penetrating shoe leather. Control methods are performed by certified individuals because of the high probability of spreading the species. Manual removals and chemical treatments are used to remove the plants from a waterway. Eradication is difficult because seeds may lay dormant for up to 12 years. Nonetheless, removal is encouraged by Maryland Department of Natural Resources (mechanical or chemical). Removal of water chestnut from Potomac River cost millions of dollars in 1965 and was successful. It was later discovered and removed in 2014 from Potomac River by Virginia Department of Game and Inland Fisheries. In the 1990's it was also found in Bird River (near Baltimore, MD) and Sassafras River (upper Chesapeake Bay) and labor intensive removals were successful. Costs totaled $80,000 over a 10-year period (Moser 2002). A statewide plan to control water chestnut is found at:

http://www.anstaskforce.gov/Species%20plans/Water%20Chestnut%20Mgt%20Plan.pdf

Red Alert Freshwater Plants and Control/Eradication Methods

Common water-hyacinth (*Eichhornia crassipes*)—This species is native to South America, yet it has been widely introduced to North America. In 1884 the plants were given away as gifts at the World's Fair in New Orleans. The plants rapidly became a problem because of overgrowth in rivers that led to fish death and shipping hazards. The species has been controlled with chemicals, mechanical removal, and biological control agents. The species exists in Maryland, but has not been documented overwintering presumably because of its intolerance for cold weather (< 21° C).

Giant salvinia (*Salvinia molesta*)—A floating fern from southern Brazil, this species was probably introduced to the United States through the aquarium and garden-pond trade. It can also be spread by boaters. A rapidly growing plant that can double its numbers in 2 – 10 days, it completely covers waterways and shades out native aquatic plants. As it dies, decomposition of plant tissues can cause hypoxia. It does not survive below 24° F or in water that freezes during winter. Eradication is practically impossible by hand. Small infestations can be controlled by hand, however, and should be done immediately. A weevil (*Cyrtobagous salviniae*) has been introduced into 13 countries for biocontrol.

High Priority Marine Animals and Plants and Control/Eradication Methods

European green crab (*Carcinus maenas*)—Native to the Atlantic coasts of Europe and Africa, the European green crab was introduced to Massachusetts in the mid-1800's, probably through ballast water. In Maryland, the species was discovered in the coastal bays near Ocean City Inlet around 1996. It is currently found in Isle of Wight Bay. The species commonly occupies rocky jetties, bulkheads, and other structures and forages over open flats and tidal marshes. Growing to a maximum size of 3 inches, green crabs can survive in a wide range of salinity and temperatures, but has poor reproduction below 20 ppt and 10° C (Hines et al., 2004). Green crabs are legally sold as bait in Maryland, yet the state recommends that unused bait be discarded on shore and not returned to the water. The loss of bait from hooks or escape of live bait is currently not monitored.

Chinese mitten crab (*Eriocheir sinesis*)—Native to Asia, this species has been reported from Chesapeake Bay. It is a small, brown crab with distinct "hairy" white-tipped claws. Only a small number of Chinese mitten crab has been collected from Chesapeake Bay since it was confirmed in 2006 at the mouth of Patapsco River. It is tolerant of variable habitat conditions, salinities, and can spread fast once established. None have been confirmed from upstream freshwater habitats where they spend most of their lives. If a Chinese mitten crab is caught, then it is encouraged that the crab be kept, kept on ice, and reported to Smithsonia Environmental Research Center. A Chinese Mitten Crab Watch has been developed to help the general public report occurrences of mitten crab:

http://www.dnr.state.md.us/dnrnews/infocus/mitten_crab.asp.

Japanese shore crab (*Hemigrapsus sanguineus*)—Native to the western North Pacific, Japanese shore crabs have been found in Isle of Wight, Sinepuxent Bay and

Chincoteague Bay of the coastal bays in Maryland. It was presumably released during bait discards. The small species (shell width < 50 mm) has light and dark bands on their legs and red spots on the claws. The species lives in shallow waters and oyster reefs, but impacts of the species are still unknown.

Red Alert Marine Animals and Plants and Control/Eradication Methods

Lionfish (*Pterois voltans* and *P. miles*)—Introduced to the South Atlantic Bight from Florida in the 1980's or 1990's either because Hurricane Andrew destroyed an aquarium or because of intentional, illegal introductions prior to the hurricane (Schofield 2009). The species is native to the Indo-Pacific. The species has quickly colonized reefs of the South Atlantic Bight and has spread to the Caribbean. In rare cases, young lionfish have traveled along the Gulf Stream and northward to the Long Island Sound (Fire Island, New York). Currently, the species is continuously distributed from Miami, Florida to Cape Hatteras, North Carolina. While the species has not been collected in Maryland waters, it is possible that changes in the direction of the Gulf Stream or warming waters will result in lionfish colonizing reefs offshore and near Assateague Island or Ocean City, Maryland. The species can negatively impact reef communities through predation (Albins and Hixon 2008) and poses a human health risk because of its venomous spines.

The Asian horseshoe crab (*Tachypleus* spp.)—Imported by the bait industry and if introduced, this species could also introduce non-native parasites and pathogens that threaten native horseshoe crab (or other species). These parasites and pathogens could also cause human health risks from neurotoxins (tetrodotoxin) that are found in one of the Asian species. For these reasons, Maryland banned the import of Asian horseshoe crabs in 2013 (Classification of Non-native Aquatic Organisms. Annotated Code of Maryland § 08.02.19.04).

MANAGEMENT PLAN

Plan Goal

The goal of the Maryland ANSP is to fully implement a coordinated strategy that minimizes risk of establishment by ANS along known pathways by 2020 and when possible, stop the spread of ANS in Maryland and eradicate or control ANS to a minimal level of impact.

Plan Objectives

1) **Prevent** new and additional introductions of ANS to Maryland waters;

2) Establish an early **detection and rapid response** mechanism to find, contain, and/or eradicate newly introduced species;

3) **Control and slow the spread** of existing ANS in Maryland.

Plan Strategies, Actions and Funding

1. Prevent new and additional ANS introductions to Maryland waters

1.1 Strategy Assess relative risk of new aquatic species introductions

1.1.1 Action

Develop greater coordination with neighboring state agencies and among Maryland agencies and organizations involved with invasive species management. Use existing ANS Management Plans from neighboring states to identify lead agencies and contact information of individuals responsible for ANS management. Ensure representation of neighboring jurisdictions and Maryland agencies at MDDNR ISMT meetings.

1.1.2 Action

Review and update lists of red alert and high priority species listed in Appendix 1. The list can be reviewed at annual meetings of MDDNR ISMT and added to, as appropriate.

1.1.3 Action

Review and recommend use of an appropriate risk assessment when new aquatic species are detected, and for red alert and high priority species listed in Appendix 1. Risk assessments include aquatic animal risk assessment, pathogen risk assessments, STAIR, and FISK (see Implementation Table). Reviews may be performed during annual MDDNR ISMT meetings, with recommendations provided by the Chair.

1.1.4 Action

Rank red alert and high priority species listed in Appendix 1 according to risk and generate species-specific actions for prevention or control for species with high levels of risk. Of listed red alert and high priority species in Maryland, the percentage of species with risk assessments is calculated and tracked across years. The risk assessments will be provided on-line and the general public. Risk assessments can be provided to aquaculture permitting authorities or other parties with interest within MDDNR, when needed.

1.1.5 Action

Develop a distribution list of State partners with ANS information websites. Provide webmasters with risk assessments and rankings of species for on-line distribution.

1.2 Strategy Analyze and assess risk of vector pathways of introduction

1.2.1 Action

Use NISC/ANSTF pathway analysis and ranking system to rank and determine the relative risk of ANS introduction through known vector pathways (Orr et al. 2005). The ISMT will coordinate the use of or use procedures developed by NISC and ANSTF to rank pathways.

1.2.2 Action

Review and update pathway rankings as new information becomes available. With annual meetings of ISMT and as the ANSP is reviewed (see Plan Review), the rankings of pathways may be updated based upon information learned from the NISC/ANSTF pathway analysis and ranking system.

1.2.3 Action

Develop a distribution list of State partners with ANS information websites and distribute vector pathway list and rankings to webmasters.

1.2.4 Action

Support research to identify critical control points for each known vector pathway (Whitehead and Orriss 2015) by identifying: 1) stakeholders, including a list of wholesale and retail distributors of live animals; 2) socioeconomic and cultural barriers to interruption of vector pathways; and 3) species of greatest risk or concern. The number of pathways identified in the ANS Management Plan with the necessary details (i.e., critical points, stakeholders, barriers, high priority or red alert species) will be tallied to improve that number over time by ISMT. Research may be conducted, as funding permits, to identify critical control points by State partners.

1.3 Strategy Take actions to remove or minimize risk of new species introductions or within pathways of introduction

1.3.1 Action

For some impounded waters such as Deep Creek Lake, create a watercraft inspection process that includes visual inspection, vessel movement and docking history, boat washing stations, and/or penalties for launching vessels that carry potential ANS. For each top ranked pathway or species, develop and implement a management plan for boat inspection stations for highly prioritized pathways and high priority or red alert species.

1.3.2 Action

Assess existing laws and regulations to determine their adequacy for preventing introduction or spread of ANS. A committee will be established and/or an intern will be hired to review proposed laws or regulation that relate to ANS and describe laws or regulation in future revisions. Meet with Natural Resources Police to ensure that existing legislation and regulation is enforceable and understandable.

1.3.3 Action

Hold stakeholder meetings to develop legislation or regulation to reduce, minimize or eliminate ANS introductions. Meet with Natural Resources Police to ensure that developing legislation and regulation is enforceable and understandable.

1.4 Strategy Design and disseminate outreach and educational tools to raise awareness of the consequences of ANS introduction.

1.4.1 Action

Develop or identify education programs aimed at preventing introduction of new species using on-line materials, materials for zoos and aquariums, and guest lecturers or materials for K-12, community colleges, or 4-year universities. Where possible, the type and number of education programs developed to slow spread of ANS will be determined for State partners. These education programs maybe referenced on-line with the MDDNR ISMT website. Build relationships between MDDNR and non-profit organizations to facilitate the transfer of education or outreach materials regarding ANS.

1.4.2 Action

Create outreach and teaching materials in appropriate languages for targeted stakeholder groups, including fishing organizations, outdoor clubs, and corporate groups. Outreach and teaching materials may be catalogued by target audience for dissemination. The availability of such materials for various audiences will be determined during annual MDDNR ISMT meetings to identify gaps in outreach. The distribution of these materials in the State and mid-Atlantic Region will be monitored to expand the number and distribution over time

1.4.3 Action

Develop and disseminate outreach materials for religious groups who routinely engage in "mercy releases" to educate them about the ecological and economic consequences of new species introductions. The number and diversity of products for different cultures and faith based organizations will be determined to identify existing gaps in outreach offerings.

1.5 Funding

The cost of the accomplishing all proposed solutions for regulating pathways and assessing risk of introductions is estimated at $780,000/yr. Some of this funding is not continuous funding, particularly that for education and outreach wherein supplies may not need to be purchased each year. There is in-kind support from the MDDNR ISMT (salary of biologists, printing costs for reports). Funding sources include the State of Maryland and ANSTF.

2. Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species.

2.1 Strategy Compare existing databases and reporting systems to adopt a statewide database for newly introduced species.

2.1.1 Action

Identify and describe available reporting databases. The following databases will be reviewed by ISMT for their current and potential use: The Early Detection and Distribution Mapping System, www.eddmaps.org; iMapInvasives, www.impainvasives.org; National Exotic Marine and Estuarine Species Information System (NEMESIS), invasions.si.edu/nemesis; USGS Nonindigenous Aquatic Species (NAS) Database, nas.er.usgs.gov.

2.1.2 Action

Adopt and use a reporting database that is a searchable repository for observations of new species introductions. An on-line service will be identified or developed (if necessary) to support statewide needs. Participation in the service will be measured as information acquired.

2.1.3 Action

Periodically assess availability of new reporting databases to improve simplicity and efficacy of reporting. During review of the ANSP (see Plan Review), the availability of new reporting databases will be identified and discussed for inclusion as part of the review process

2.2 Strategy Engage Maryland public by establishing a citizen-science, newly introduced species detection program for targeted watersheds.

2.2.1 Action

Develop a social media platform to assist the public in reporting new species occurrences and incorporate that information into the reporting database. A social media platform such as Maryland DNR's Anglers' Log can be used to report and provide pictures of ANS (fishingreports.dnr@maryland.gov). The number of Maryland ANS reported using the social media platform can be quantified to help assess its value.

2.2.2 Action

Advertise the citizen-science program and train stewards to identify native or existing species correctly. Citizen-science programs such as the Maryland Naturalist program and Maryland's Envirothon may infuse both native species and ANS identification. Some information is available on-line via fact sheets provided on the MDDNR website. Additionally, participation in Maryland's State Fair can alsopromote awareness and identification of native species and ANS.

2.3 Strategy Establish eDNA testing capabilities or program within Maryland waters.

2.3.1 Action

Assess feasibility and statistical reliability of using and eDNA detection system in Maryland waters for red alert species. To evaluate an eDNA system, a summary of literature reviews and on-going research by University of Notre Dame.

2.4 Strategy Establish a Rapid Response Plan for newly introduced species, utilizing the Incident Command System structure.

2.4.1 Action

Identify relevant federal, state, regional and private organizations for an Incident Command System (see Appendix 2). The ISMT will use Appendices herein to develop a table of such organizations and the pathways for which they have responsibility. This table will be added to the ANSP.

2.4.2 Action

Develop and/or adopt a Rapid Response Plan for Maryland using Smits and Moser (2009), which encourages an appropriate coordinating agency and establishes an Incident Command System team when implementing the rapid response. The number of incidents within a year will be monitored over time and will be noted in future revisions of this ANSP.

2.4.3 Action

Identify funding sources for supporting rapid response activities. A list of funding sources are identified within this ANSP, but more may be identified during annual ISMT meetings. These funding sources will be amended to the Implementation Table in the ANSP along with the action that may be addressed with the money as the ANSP is reviewed.

2.4.4 Action

Routinely train Incident Command Team members for a rapid response (see http://training/fema.gov/IS/). Positions will be identified for the rapid response plan, once adopted, by ISMT and State partners, when needed. The number of filled positions and the training of those positions will be tracked as a measure of success.

2.4.5 Action

Identify laws that require notification of ANS detection to the public, to law enforcement, and to federal authorities. A committee will be established to review proposed laws or regulation that relate to ANS, when needed.

2.5 Funding

The estimated cost for achieving these actions is $50,000/yr. There is in-kind support by MDDNR for development of a social media platform that can be utilized by an informed public to report exotic species. This notification system could depend upon the public's knowledge of ANS, which could require funding for signs and education, or simply on the public's willingness to report an unknown species. There are also numerous state and university fish surveys that may lead to detection of exotic species. Some surveys have a long history in Maryland, including: the Striped Bass Seine Survey, the Tidal Bass Survey, Maryland Biological Stream Survey, and Coastal Bay Program's surveys. Faculty of Maryland universities report catch results of their aquatic surveys as a condition of their scientific collection permit issued by MDDNR. There is in-kind support to initiate a Rapid Response Plan, but no funding to foster collaboration among inter-agency officials and no funding for training individuals who participate with the Incident Command Team. Potential funding sources include the State of Maryland, Maryland SeaGrant, and ANSTF.

3. Control and slow spread of existing ANS species

3.1 Strategy For high priority ANS, determine if harvest and biomass removal are effective tools to control and slow the spread of ANS.

3.1.1 Action

Conduct studies and review studies for high priority species to determine the most effective tools for removing ANS. These projects, when funded, will be evaluated by analyzing data and determining if the specific objectives of the project are met. For example, an objective may be to reduce annual biomass and the level of reduction can be determined by comparing annual estimates of biomass.

3.2 Strategy Enact statutes and regulations that criminalize, stigmatize and exact penalties for human-mediated spread of ANS.

3.2.1 Action

Implement laws that interrupt pathways of introduction that cause ANS range expansions. The Natural Resources Police report violations of laws and these violations may be categorized into those that interrupt pathways. Pathways with numerous violations may be prioritized (see also Strategy 1.2).

3.2.2 Action

Examine existing laws for considering new or revised regulations that improve control or slow spread of existing ANS by using methods employed by Environmental Law Institute. A list of existing laws aimed at controlling and slowing spread of existing ANS will be created by ISMT and provided online via the MDDNR Invasive Species website.

3.2.3 Action

Develop training materials or programs for training Natural Resource Police officers in ANS identification and law. Routine engagements with law enforcement will provide current information on status of ANS. Some training information is available as fact sheets and on-line via the MDDNR Invasive Species website. These engagements will be made annually or as needed to improve training of officers. Training will be provided by appropriate staff, such as members of ISMT.

3.3 Strategy

Implement removal or containment actions to control biomass or prevent natural spread

3.3.1 Action

Identify high priority ANS that can be routinely, cost-effectively, and practically controlled for biomass and implement strategies that engage the public or partners in those control efforts. This ANSP provides a listing of high priority ANS and potential control methods for those species. Strategies that can be additionally used include cooperative messaging on packaging on live seafood, in pet stores, incentives such as a bait buy-back program, or harvest incentives. The use of these strategies depends on available funding and cooperation among stakeholders.

3.3.2 Action

Restore ecosystems impacted by ANS using native species, when necessary, to help produce natural communities and reduce long-term maintenance costs. Restoration with non-ANS species may be necessary to control the impact by ANS. A review of the level to which habitats can be restored from ANS impacts should be conducted to establish management targets or expectations from restoration. Research projects aimed at restoration may then be conducted with specific objectives achieved for each study.

3.3.3 Action

Report level of biomass removed to stakeholders, along with costs. Level of biomass harvested for selected high priority ANS can be reported each year on-line or in technical reports. The MDDNR Invasive Species website provides a framework for reporting actions taken to control high priority ANS.

3.4 Funding

Requested funding for accomplishing these actions is $175,000/yr and this funding is requested on a continuous basis to fund staffing and control mechanisms. There is no dedicated financial support to slow the spread or control biomass of aquatic nuisance and well-established species. The cost of implementing control strategies could be in the millions, depending on the species or waterway. Funding sources may include those from ANSTF, Sport Fish Restoration and Conservation Act, Maryland SeaGrant, USFWS National Fish and Wildlife Foundation, or State of Maryland.

Implementation Table. The success of a strategy to meet its objective will be evaluated with measurable results. The measurable results are detailed in Program Evaluation. Possible sources of funding for implementing actions in the strategy are provided along with an estimated additional cost (in parentheses). The Lead Organization (LO) is the organization with the lead responsibility for implementing the action. The Cooperating Organization (CO) are organizations that support or are involved in the action, along with the dollar and full time equivalent position contribution given in parentheses.

Objective	**Strategy**	**Action**	**Program Evaluation**	**Funding**	**LO**	**CO**
1. Prevent new and additional ANS introductions to Maryland waters.	1.1 Assess relative risk of new aquatic species introductions.	1.1.1 Develop greater coordination with neighboring state agencies.	Develop greater coordination with neighboring state agencies and among Maryland agencies and organizations involved with invasive species management. Use existing ANS Management Plans from neighboring states to identify lead agencies and contact information of individuals responsible for ANS management. Ensure representation of neighboring jurisdictions and Maryland agencies at MDDNR ISMT meetings.	MDDNR ($0)		
1. Prevent new and additional ANS introductions to Maryland waters.	1.1 Assess relative risk of new aquatic species introductions	1.1.2 Review and update lists of red alert and high priority species listed in Appendix 1.	The list can be reviewed at annual meetings of MDDNR ISMT and added to, as appropriate.	MDDNR ($0)	MDDNR	
1. Prevent new and additional ANS introductions to Maryland waters.	1.1 Assess relative risk of new aquatic species introductions	1.1.3 Review and recommend use of an appropriate risk assessment when new aquatic species are detected, and for red alert and high priority species listed in Appendix 1.	Risk assessments include aquatic animal risk assessment, pathogen risk assessments, STAIR, and FISK (see Implementation Table). Reviews may be performed during annual MDDNR ISMT meetings, with recommendations provided by the Chair. Risk assessments will be provided to aquaculture permitting authorities within MDDNR, when needed.	MDDNR ($0)	MDDNR	

1. Prevent new and additional ANS introductions to Maryland waters.	1.1 Assess relative risk of new aquatic species introductions	1.1.4 Rank red alert and high priority species listed in Appendix 1 according to risk and generate species-specific actions for prevention or control for species with high levels of risk.	Of listed red alert and high priority species in Maryland, the percentage of species with risk assessments is calculated and tracked across years. The risk assessments will be provided on-line and the general public. Risk assessments can be provided to aquaculture permitting authorities or other parties with interest within MDDNR, when needed.	MDDNR, ANSTF ($15,000)		
1. Prevent new and additional ANS introductions to Maryland waters.	1.1 Assess relative risk of new aquatic species introductions	1.1.5 Establish online availability of species list, risk assessment results, and rankings.	Develop a distribution list of State partners with ANS information websites. Provide webmasters with risk assessments and rankings of species for on-line distribution.	MDDNR, ($0)	MDDNR	
1. Prevent new and additional ANS introductions to Maryland waters.	1.2 Analyze and assess risk of vector pathways of introduction.	1.2.1 Use NISC/ANSTF pathway analysis and ranking system to rank and determine the relative risk of ANS introduction through known vector pathways.	The ISMT will coordinate the use of or use procedures developed by NISC and ANSTF to rank pathways (Orr et al. 2005).	MDDNR, ANSTF ($5000/yr)	MDDNR (1 staff)	
1. Prevent new and additional ANS introductions to Maryland waters.	1.2 Analyze and assess risk of vector pathways of introduction.	1.2.2 Review and update pathway rankings as new information becomes available.	With annual meetings of ISMT and as the ANSP is reviewed (see Plan Review), the rankings of pathways will be updated based upon information learned from the NISC/ANSTF pathway analysis and ranking system.	MDDNR ($0)	MDDNR	
1. Prevent new and additional ANS introductions to Maryland waters.	1.2 Analyze and assess risk of vector pathways of introduction.	1.2.3 Establish online availability of vector pathway list and rankings.	Develop a distribution list of State partners with ANS information websites and distribute vector pathway list and rankings to webmasters.	MDDNR ($0)		MDDNR (1 staff)

1. Prevent new and additional ANS introductions to Maryland waters.	1.2 Analyze and assess risk of vector pathways of introduction.	1.2.4 Support research to identify critical control points for priority vector pathways by identifying: 1) stakeholders, including a list of wholesale and retail distributors of live animals; 2) socioeconomic and cultural barriers to interruption of vector pathways; and 3) species of greatest risk or concern.	The number of pathways identified in the ANS Management Plan with the necessary details (i.e., critical points, stakeholders, barriers, high priority or red alert species) will be tallied to improve that number over time by ISMT. Research may be conducted, as funding permits, to identify critical control points by State partners.	MDDNR, ANSTF ($30,000/yr)		
1. Prevent new and additional ANS introductions to Maryland waters.	1.3 Take actions to remove or minimize risk of new species introductions or within pathways of introduction.	1.3.1 For some impounded waters such as Deep Creek Lake, create a watercraft inspection process that includes visual inspection, vessel movement and docking history, boat washing stations, and/or penalties for launching vessels that carry potential ANS.	For each top ranked pathway or species, develop and implement a management plan for boat inspection stations for highly prioritized pathways and high priority or red alert species.	MDDNR, ANSTF ($500,000/yr)	MDDNR	
1. Prevent new and additional ANS introductions to Maryland waters.	1.3 Take actions to remove or minimize risk of new species introductions or within pathways of introduction.	1.3.2 Assess existing laws and regulations to determine their adequacy for preventing introduction or spread of ANS.	A committee will be established and/or an intern will be hired to review proposed laws or regulation that relate to ANS and describe laws or regulation in future revisions. Meet with Natural Resources Police to ensure that existing legislation and regulation is enforceable and understandable.	MDDNR, ANSTF ($5000/yr)	MDDNR	
1. Prevent new and additional ANS introductions to Maryland waters.	1.3 Take actions to remove or minimize risk of new species introductions or within pathways of introduction.	1.3.3 Develop legislation or regulation to reduce, minimize or eliminate ANS introductions.	Meet with Natural Resources Police to ensure that developing legislation and regulation is enforceable and understandable.	MDDNR ($0)	MDDNR	

1. Prevent new and additional ANS introductions to Maryland waters.	1.4 Design and disseminate outreach and educational tools to raise awareness of the consequences of ANS introduction.	1.4.1 Develop or identify education programs aimed at preventing introduction of new species using on-line materials, materials for zoos and aquariums, and guest lecturers or materials for K-12, community colleges, or 4-year universities.	Where possible, the type and number of education programs developed to slow spread of ANS will be determined for State partners. These education programs may be referenced on-line with the MDDNR ISMT website. Build relationships between MDDNR and non-profit organizations to facilitate the transfer of education or outreach materials regarding ANS.	MDDNR, ANSTF ($100,000/yr)		MDDNR (1 staff)
1. Prevent new and additional ANS introductions to Maryland waters.	1.4 Design and disseminate outreach and educational tools to raise awareness of the consequences of ANS introduction.	1.4.2 Create outreach and teaching materials in appropriate languages for targeted stakeholder groups, including fishing organizations, outdoor clubs, and corporate groups; provide materials via world wide web as, http://dnr2.maryland.gov/ccs/Pages/InvasivePlantControl.aspx or http://dnr2.maryland.gov/invasives/Pages/default.aspx.	Outreach and teaching materials may be catalogued by target audience for dissemination. The availability of such materials for various audiences will be determined during annual MDDNR ISMT meetings to identify gaps in outreach. The distribution of these materials in the State and mid-Atlantic Region will be monitored to expand the number and distribution over time	MDDNR, ANSTF ($100,000/yr)		MDDNR (1 staff)
1. Prevent new and additional ANS introductions to Maryland waters.	1.4 Design and disseminate outreach and educational tools to raise awareness of the consequences of ANS introduction.	1.4.3 Develop and disseminate outreach materials for religious groups who routinely engage in "mercy releases" to educate them about the ecological and economic consequences of new species introductions.	The number and diversity of products for different cultures and faith based organizations will be determined to identify existing gaps in outreach offerings.	MDDNR, ANSTF ($25,000/yr)		MDDNR (1 staff)

Objective	Strategy	Action	Program Evaluation	Funding	LO	CO
2. Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species.	2.1 Compare existing databases and reporting systems to adopt a statewide database for newly introduced species.	2.1.1 Identify and describe available reporting databases.	The following databases will be reviewed by ISMT for their current and potential use: The Early Detection and Distribution Mapping System, www.eddmaps.org; iMapInvasives, www.impainvasives.org; National Exotic Marine and Estuarine Species Information System (NEMESIS), invasions.si.edu/nemesis; USGS Nonindigenous Aquatic Species (NAS) Database, nas.er.usgs.gov.	MDDNR ($0)	MDDNR	
2. Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species.	2.1 Compare existing databases and reporting systems to adopt a statewide database for newly introduced species.	2.1.2 Adopt and use a reporting database that is a searchable repository for observations of new species introductions.	An on-line service will be identified or developed (if necessary) to support statewide needs. Participation in the service will be measured as information acquired.	MDDNR ($0)	MDDNR	
2. Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species.	2.1 Compare existing databases and reporting systems to adopt a statewide database for newly introduced species.	2.1.3 Periodically assess availability of new reporting databases to improve simplicity and efficacy of reporting.	During review of the ANSP (see Plan Review), the availability of new reporting databases will be identified and discussed for inclusion as part of the review process	MDDNR ($0)		

2. Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species.	2.2 Engage Maryland public by establishing a citizen-science, newly introduced species detection program for targeted watersheds.	2.2.1 Develop a social media platform to assist the public in reporting new species occurrences and incorporate that information into the reporting database.	A social media platform such as Maryland DNR's Anglers' Log can be used to report and provide pictures of ANS,fishingreports.dnr@maryland.gov. The number of Maryland ANS reported using the social media platform can be quantified to help assess its value.	MDDNR, MDSG, ANSTF ($15,000/yr)	MDDNR	
2. Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species.	2.2 Engage Maryland public by establishing a citizen-science, newly introduced species detection program for targeted watersheds.	2.2.2 Advertise the citizen-science program and train stewards to identify native or existing species correctly.	Citizen-science programs such as the Maryland Naturalist program and Maryland's Envirothon include both native species and ANS identification. Some information is available online via fact sheets provided on the MDDNR website. Additionally, participation in Maryland's State Fair can also promote awareness and identification of native species and ANS.	MDDNR ($0)		
2. Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species.	2.3 Establish eDNA testing capabilities or program within Maryland waters.	2.3.1 Assess feasibility and statistical reliability of using an eDNA detection system in Maryland waters for red alert species.	To evaluate an eDNA system, a summary of literature reviews and on-going research by University of Notre Dame.	MDDNR, MDSG, ANSTF ($20,000/yr)		

2. Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species.	2.4 Establish a Rapid Response Plan for newly introduced species, utilizing the Incident Command System structure.	2.4.1 Identify relevant federal, state, regional and private groups for Incident Command System (FEMA: www.fema. gov/national-incident-management-system/incident-command-system-resources).	The ISMT will use Appendices herein to develop a table of such organizations and the pathways for which they have responsibility. This table will be amended to the ANSP.	MDDNR ($0)	MDDNR	
2. Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species.	2.4 Establish a Rapid Response Plan for newly introduced species, utilizing the Incident Command System structure.	2.4.2 Develop and/or adopt a Rapid Response Plan for Maryland using Smits and Moser (2009), which encourages an appropriate coordinating agency and establishes an Incident Command System team when implementing the rapid response.	The number of incidents within a year will be monitored over time and will be noted in future revisions of this ANSP.	MDDNR ($0)	MDSG	
2. Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species.	2.4 Establish a Rapid Response Plan for newly introduced species, utilizing the Incident Command System structure.	2.4.3 Identify funding sources for supporting rapid response activities.	A list of funding sources are identified within this ANSP, but more may be identified during annual ISMT meetings. These funding sources will be amended to the Implementation Table in the ANSP along with the action that may be addressed with the money as the ANSP is reviewed.	MDDNR ($0)	MDDNR	

2. Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species.	2.4 Establish a Rapid Response Plan for newly introduced species, utilizing the Incident Command System structure.	2.4.4 Routinely train Incident Command Team members for a rapid response .	Positions will be identified for the rapid response plan, once adopted, by ISMT and State partners, when needed. The number of filled positions and the training of those positions will be tracked as a measure of success.	MDDNR, MDSG, ANSTF ($15,000/yr)	MDSG	
2. Establish an early detection and rapid response mechanism to find, contain, and/or eradicate newly introduced species.	2.4 Establish a Rapid Response Plan for newly introduced species, utilizing the Incident Command System structure.	2.4.5 Identify laws that require notification of ANS detection to the public, to law enforcement, and to federal authorities.	A committee will be established to review proposed laws or regulation that relate to ANS, when needed.	MDDNR ($0)	MDDNR	

Objective	Strategy	Action	Program Evaluation	Funding	LO	CO
3. Control and slow spread of existing ANS species	3.1 For high priority ANS, determine if harvest and biomass removal are effective tools to control and slow the spread of ANS.	3.1.1 Conduct studies and review studies for high priority species to determine the most effective tools for removing ANS.	These projects, when funded, will be evaluated by analyzing data and determining if the specific objectives of the project are met. For example, an objective may be to reduce annual biomass and the level of reduction can be determined by comparing annual estimates of biomass.	MDDNR, MDSG USFWS ($100,000/yr)		
3. Control and slow spread of existing ANS species	3.2 Enact statutes and regulations that criminalize, stigmatize and exact penalties for human-mediated spread of ANS.	3.2.1 Implement laws that interrupt pathways of introduction that cause ANS range expansions.	The Natural Resources Police report violations of laws and these violations may be categorized into those that interrupt pathways. Pathways with numerous violations may be prioritized (see also Strategy 1.2).	MDDNR ($0)	MDDNR	
3. Control and slow spread of existing ANS species	3.2 Enact statutes and regulations that criminalize, stigmatize and exact penalties for human-mediated spread of ANS.	3.2.2 Examine existing laws for considering new or revised regulations that improve control or slow spread of existing ANS by using methods employed by Environmental Law Institute.	A list of existing laws aimed at controlling and slowing spread of existing ANS will be created by ISMT and provided online via the MDDNR Invasive Species website.	MDDNR, MDSG, USFWS ($5000/yr)	MDDNR	

3. Control and slow spread of existing ANS species	3.2 Enact statutes and regulations that criminalize, stigmatize and exact penalties for human-mediated spread of ANS.	3.2.3 Develop training materials or programs for training Natural Resource Police officers in ANS identification and law.	Routine engagements with law enforcement will provide current information on status of ANS. Some training information is available as fact sheets and on-line via the MDDNR Invasive Species website. These engagements will be made annually or as needed to improve training of officers. Training will be provided by appropriate staff, such as members of ISMT.	MDDNR ($15,000)		MDDNR
3. Control and slow spread of existing ANS species	3.3 Implement removal or containment actions to control biomass or prevent natural spread.	3.3.1 Identify high priority ANS that can be routinely, cost-effectively, and practically controlled for biomass and implement strategies that engage the public or partners in those control efforts.	This ANSP provides a listing of high priority ANS and potential control methods for those species. Strategies that can be additionally used include cooperative messaging on packaging on live seafood, in pet stores, incentives such as a bait buy-back program, or harvest incentives. The use of these strategies depends on available funding and cooperation among stakeholders.	MDDNR, USFWS, MDSG, ($5,000/yr)	MDDNR	
3. Control and slow spread of existing ANS species	3.3 Implement removal or containment actions to control biomass or prevent natural spread.	3.3.2 Restore ecosystems impacted by ANS using native species, when necessary, to help produce natural communities and reduce long-term maintenance costs.	Restoration with non-ANS species may be necessary to control the impact by ANS. A review of the level to which habitats can be restored from ANS impacts should be conducted to establish management targets or expectations from restoration. Research projects aimed at restoration may then be conducted with specific objectives achieved for each study.	MDDNR, USFWS, MDSG, ANSTF ($50,000)	MDDNR	

3. Control and slow spread of existing ANS species	3.3 Implement removal or containment actions to control biomass or prevent natural spread.	3.3.3 Report level of biomass removed to stakeholders, along with costs.	Level of biomass harvested for selected high priority ANS can be reported each year on-line or in technical reports. The MDDNR Invasive Species website provides a framework for reporting actions taken to control high priority ANS.	MDDNR ($0)	MDDNR	

PRIORITIES FOR ACTION

There are 33 actions that have been identified to fully implement the ANSP. It will not be able to implement all of these actions within the 5-year span of this plan. Therefore 10 actions were prioritized below based upon their cost and necessity. All actions are considered to be very important and do not appear in priority order below.

1. Develop greater coordination with neighboring state agencies and Maryland agencies invested in invasive species management.
2. Review and recommend use of an appropriate risk assessment when new aquatic species are detected, and for red alert and high priority species listed in Appendix
3. Use NISC/ANSTF pathway analysis and ranking system to rank and determine the relative risk of ANS introduction through known vector pathways.
4. Support research to identify critical control points for priority vector pathways by identifying: 1) stakeholders, including a list of wholesale and retail distributors of live animals; 2) socioeconomic and cultural barriers to interruption of vector pathways; and 3) species of greatest risk or concern.
5. Assess existing laws and regulations to determine their adequacy for preventing introduction or spread of ANS.
6. Identify and describe available reporting databases.
7. Adopt and use a reporting database that is a searchable repository for observations of new species introductions.
8. Identify relevant federal, state, regional and private groups for Incident Command System (FEMA: www.fema. gov/national-incident-management-system/incident-command-system-resources).
9. Develop and/or adopt a Rapid Response Plan for Maryland using Smits and Moser (2009), which encourages an appropriate coordinating agency and establishes an Incident Command System team when implementing the rapid response.
10. Identify high priority ANS that can be routinely, cost-effectively, and practically controlled for biomass and implement strategies that engage the public or partners in those control efforts.

PLAN REVIEW

Periodic review of the ANSP will be the responsibility of MDDNR. The breadth and experience of MDDNR in partnership with existing authorities given in Appendix 2 will identify progress toward actions identified in the implementation table. Progress toward actions are measurable and described in the Program Evaluation section of the Implementation Table. Implementing this ANSP by 2020 will require progress toward all actions, though not all actions will have measurable or successful outcomes.

In most cases the implementation of actions depends on available funding and staffing. Funding from State and Federal sources depends on budgets created by legislatures whose priorities may be different than those expressed in this ANSP. In cases when additional cost is listed as $0, the implementation of the action can depend on priorities of the lead organization. While additional money may not be needed to implement the action, priorities for staff time may be different than those expressed in this ANSP. When funding and staffing is sufficiently available, the success of projects aimed at controlling biomass or impacts by ANS also depends on the habitat or environmental factors. The ability to remove biomass of ANS or to minimize impacts and spread of ANS can depend on weather, flooding, water temperatures, and access to areas by humans. While successful implementation of action items is challenging, progress over time will be noted within the framework of the ANSP review, which is a transparent evolution of work toward achieving objectives and maximizing success of reaching goals set herein.

Measurable output from Program Evaluation will be included in future reviews of the ANSP. Significant revisions will be added to the course of plan development in Appendix 3. If required, public comments regarding actions or revisions will be appended to Appendix 4. Considerations for review and revision will address:

- Updating the Implementation Table with achieved or partially achieved actions within objective.
- Noting new vector pathways
- Noting new efforts to prevent introductions using decontamination or other methods
- Noting the number of new introductions
- Updating the list of known ANS in Maryland (see Appendix 3) with total acreage of habitat occupied by the ANS in Maryland (or a specified subwatershed); and/or the relative abundance index or abundance or ranked abundance of the ANS in Maryland (or a specified subwatershed)
- Noting whether or not ANS has led to a listing of native species as a Federal and/or State species in need of conservation.
- Nothing whether natural, climatic ecosystem changes have reduced effectiveness of management actions.
- Revising gaps and challenges in regional, State, or Federal regulations related to ANS management

LITERATURE CITED

ABA (American Bass Anglers). 2014. *Louisiana to stock larger Florida Bass*. Press Release, http://www.americanbassanglers.com/BWS/newsdetails.php?news_id=1104.

ANSTF (Aquatic Nuisance Species Task Force). 1994. *Report to Congress: Findings, Conclusions, and Recommendations of the Intentional Introductions Policy Review.* http://www.anstaskforce.gov/Documents/Intentional_Introductions_Policy_Review.pdf.

AP (Associated Press). 2005. MD Considers reeling in use of 'nuclear' worms. Bay Journal, June 01 2005. (accessed December 2015, website: http://www.bayjournal.com/article/md_considers_reeling_in_use_of_nuclear_worm)

Albins, M.A. and M.A. Hixon. 2008. *Invasive Indo-Pacific lionfish* Pterois volitans *reduce recruitment of Atlantic coral-reef fishes*. Marine Ecology Progress Series 367: 233-238.

Bartholomew, J.L. and P.W. Reno. 2002. *The history and dissemination of whirling disease*. American Fisheries Society Symposium 29:3-24.

Beck, K.G., K. Zimmerman, J.D. Schardt, J. Stone, R.R. Lukens, S. Reichard, J. Randall, A. A. Cangelosi, D. Cooper, and J.P. Thompson. 2008. *Invasive species defined in a policy context: recommendations from the federal invasive species advisory committee.* Invasive Plant Science and Management 1:414-421

Bothwell, M.L., D.R. Lynch, H. Wright, and J. Deniseger. 2009. *On the boots of fishermen: The history of Didymo blooms on Vancouver Island, British Columbia*. Fisheries 34:382-388.

Burreson, E.M., N.A. Stokes, and C.S. Friedman. 2000. *Increased virulence in an introduced pathogen:* Haplosporidium nelsoni *(MSX) in the eastern oyster* Crassostrea virginica*.* Journal of Aquatic Animal Health 12:1-8.

Campbell, F. and P. Kriesch. 2003. Final report by the National Invasive Species Council's Invasive Species Pathways Team of the Prevention Working Group. www.invasivespeciesinfo.gov/council/wrkgrps.shtml.

Carlton, J.T. and G.M. Ruiz. 2005. "Vector science and integrated vector management in bioinvasion ecology: Conceptual frameworks." Pages 36-58 *in* Mooney, H.A., R.N. Mack, J.A. McNeely, L.E. Neville, P.J. Schei, and J.K. Waage, editors. *Invasive Alien Species: A New Synthesis*. Island Press Publishers, Washington, D.C.

Chan, S.S., T. Siemens, J. Adams, C. Jacoby, W. Wong, and R. Goettel. 2012. *Opportunity for integrated vector management: Reducing the potential for schools and biological science suppliers as pathways for invasive species*. Ecological Society of America Annual Meeting, 2012. Portland, Oregon.

Chapman, J.W., T.W. Miller, and E.V. Coan. 2003. *Live seafood species as recipes for invasion*. Conservation Biology 17:1386-1395.

Chen, P., E.O. Wiley, K.M. Mcnyset. 2007. *Ecological niche modeling as a predictive tool: Silver and bighead carps in North America*. Biological Invasions 9:43-51.

Christmas, J., R. Eades, D. Cincotta, A. Shiels, R. Miller, J. Siemien, T. Sinnott, and P. Fuller. 1998. "History, management, and status of introduced fishes in the Chesapeake Bay Basin." Pages 97-116 *in* G.D. Therres, editor. *Conservation of Biological Diversity: A Key to the Restoration of the Chesapeake Bay Ecosystem and Beyond*. Maryland Department of Natural Resources, Annapolis.

Costil, K. G.B.J. Dussart, and J. Daguzan. 2001. *Biodiversity of aquatic gastropods in the Mont St-Michel basin (France) in relation to salinity and drying habitats*. Biodiversity and Conservation 10: 1-18.

Cooke, S.L. and W.R. Hill. 2010. *Can filter-feeding Asian carp invade the Laurentian Great Lakes?* A bioenergetic modeling exercise. Freshwater Biology 10:2138-2152.

Dakin, E.E., B.A. Porter, B.J. Freeman, and J.M. Long. 2015. "Hybridization threatens shoal bass populations in the upper Chattahoochee River basin." Pages 491-502 *in* M.D. Tringali, J.M. Long, T.W. Birdsong, and M.S. Allen, editors. *Black Bass Diversity: Multidisciplinary Science for Conservation*. American Fisheries Society, Symposium 82, Bethesda, Maryland.

Daniels, R.A. 2001. *Untested assumptions: the role of canals in the dispersal of sea lamprey, alewife, and other fishes in the eastern United States.* Environmental Biology of Fishes 60:309-329.

Davidson, I.C., and C. Simkanin. 2012. *The biology of ballast water 25 years later.* Biological Invasions 14:9-13.

Davis, M.A. 2003. Biotic globalization: *Does competition from introduced species threaten biodiversity?* Bioscience 53:481-489.

Duggan, I.C., C.A.M. Rixon, and H.J. MacIsaac. 2006. *Popularity and propagule pressure: determinants of introduction and establishment of aquarium fish.* Biological Invasions 8:377-382.

EPA (Environmental Protection Agency). 2008. *Effects of climate change for aquatic invasive species and implications for management and research.* National Center for Environmental Assessment, Washington, DC; EPA/600/R-08/014. Available from the National Technical Information Service, Springfield, VA, and online at http://www.epa.gov/ncea.

Fernald, R.T., and B.T. Watson. 2005. *Millbrook quarry zebra mussel and quagga mussel eradication.* U.S. Fish and Wildlife Service Final Environmental Assessment. Virginia Department of Game and Inland Fisheries, Wildlife Diversity Division, Richmond, Virginia 112 pp.

Fincham, M.W. 2009. Travels with *Hydrilla*: *The unnatural history of an accidental invader.* Chesapeake Quarterly 8: 14-16.

Fofonoff, P., Ruiz, G.M., Steves, B. and Carlton, J.T. 2003. "In Ships or on Ships? Mechanisms of transfer and invasion for nonnative species to the coasts of North America." Pages 152-182 *in*: Ruiz, G.M. and Carlton, J.T., editors. *Invasive species: vectors and management strategies.* Island Press, Washington, D.C.

Fuller, P.L. 2003. "Freshwater aquatic vertebrate introductions in the United States: Patterns and pathways." Pages 123 - 151 *in*: Ruiz, G.M. and Carlton, J.T., editors, *Invasive Species: Vectors and Management Strategies*. Island Press, Washington, D.C.

Fuller, P. and M.E. Neilson. 2015. *The U.S. Geological Survey's Nonindigenous Aquatic Species Database: over thirty years of tracking introduced aquatic species in the United States (and counting)*. Management of Biological Invasions 6:159-170.

Goodchild, C.D. 2000. "Ecological impacts of introductions associated with the use of live bait." Pages 181-202 *in* Claudi, R. and J.H. Leach, editors. *Nonindigenous Freshwater Organisms: Vectors, Biology, and Impacts*. Lewis Publishers, Boca Raton, Florida.

Gozlan, R.E. 2008. *Introduction of non-native freshwater fish: is it all bad?* Fish and Fisheries 9:106-115.

Gérard, C., A. Blanc, and K. Costil. 2003. Potamopyrgus antipodarum *(Mollusca: Hydrobiidae) in continental aquatic gastropod communities: impact of salinity and trematode parasitism.* Hydrobiologia 493:167-172.

Grosholz, E., R.E. Crafton, R.E. Fontana, J.R. Pasari, S.L. Williams, and C.J. Zabin. 2015. *Aquaculture as a vector for marine invasions in California*. Biological Invasions 17:1471-1484.

Hardin, S. and J.E. Hill. 2012. *Risk analysis of Barramundi Perch* Lates calcarifer *aquaculture in Florida*. North American Journal of Fisheries Management 32:577-585.

Haska, C.L., C. Yarish, G. Kraemer, N. Blaschik, R. Whitlatch, H. Zhang, and S. Lin. 2012. *Bait worm packaging as a potential vector of invasive species*. Biological Invasions 14:481-493.

Hewitt, C. and M. Campbell. 2010. *Mechanisms for the prevention of marine bioinvasions for better biosecurity*. Marine Pollution Bulletin 22:27-30.

Hill, J.E. 2011. *Emerging issues regarding non-native species for aquaculture*. U.S. Department of Agriculture, National Institute of Food and Agriculture, Southern Regional Aquaculture Center Publication No. 4305.

Hines, A.H., G.M. Ruiz, N.G. Hitchcock, and C. DeRivera. 2004. *Projecting range expansion of invasive European green crabs (*Carcinus maenas*) to Alaska: Temperature and salinity tolerance of larvae*. Smithsonian Environmental Research Center, Edgewater, MD.

Hobbs, H.H., III, J.P. Jass, and J.V. Huner. 1989. *A review of global crayfish introductions with particular emphasis on two North American species (Decapoda, Cambaridae)*. Crustaceana 56:299-316.

Holeck, K., E.L. Mills, H.J. MacIsaac, M. Dochoda, R.I. Colautti, and A. Ricciardi. 2004. *Bridging troubled waters: Understanding links between biological invasions, transoceanic shipping, and other entry vectors in the Laurentian Great Lakes*. Bioscience 10:919-929.

Jackson, D.A. 2002. "Ecological effects of *Micropterus* introductions: the dark side of black bass." Pages 221-232 *in*: Phillip, D.P. and Ridgway, M.S., editors. *Black Bass: Ecology Conservation, and Management*. American Fisheries Society Symposium 31, Bethesda, MD.

Jerde, C.L., A.R. Mahon, W.L. Chadderton, and D.M. Lodge. 2011. *"Sight-unseen" detection of rare aquatic species using environmental DNA.* Conservation Letters 4:150-157.

Keller, R.P. and D.M. Lodge. 2007. *Species invasions from commerce in live aquatic organisms: Problems and possible solutions*. BioScience 57:428-436.

Kerr, S.J., C.S. Brousseau, and M. Muschett. 2005. *Invasive aquatic species in Ontario: A review and analysis of potential pathways for introduction*. Fisheries 30:21-30.

Kilian, J.V., R.J. Klauda, S. Widman, M. Kashiwagi, R. Bourquin, S. Weglein, and J. Schuster. 2012. *An assessment of a bait industry and angler behavior as a vector of invasive species*. Biological Invasions14:1469-1481.

Kilian, J.V., A.J. Becker, S.A. Stranko, M. Ashton, R.J. Klauda, J. Gerber, and M. Hurd. 2010. *The status and distribution of Maryland crayfishes*. Southeastern Naturalist 9 (Special Issue 3):11-32.

Kilian, J.V., J. Frentress, R.J. Klauda, A.J. Becker, and S.A. Stranko. 2009. *The*

Invasion of Procambarus clarkii *(Decapoda: Cambaridae) into Maryland streams following its introduction in outdoor aquaculture ponds*. Northeastern Naturalist 16:655-663.

Kohler, C.C. and J.G. Stanley. 1984. "Implementation of a review and decision model for evaluating proposed introductions of aquatic organisms in Europe and North America." Pages 541 - 549 *in*: *Documents presented at the symposium on stock enhancement in the management of freshwater fisheries*. Food and Agriculture Organization, http://www.fao.org/3/a-ae997b.pdf#page=298.

Kolar, C.S. and D.M. Lodge. 2002. *Ecological predictions and risk assessment for alien fishes in North America*. Science 298:1233-1236.

Kraus, R.T. and R.C. Jones. 2011. *Fish abundances in shoreline habitats and submerged aquatic vegetation in a tidal freshwater embayment of the Potomac River*. Environmental Monitoring and Assessment DOI 10.1007/s10661-011-2192-6.

Kumar, A.B. 2000. *Exotic fishes and freshwater fish diversity*. Zoos' Print Journal 15:363-367.

Laikre, L., M.K. Schwartz, R.S. Waples, N. Ryman, and he GeM Working Group. 2010. *Compromising genetic diversity in the wild: unmonitored large-scale release of plants and animals*. Trends in Ecology and Evolution 25: 520-529.

Lapointe, N.W.R., J.S. Odenkirk, and P.L. Angermeier. 2013. *Seasonal movement, dispersal, and home range of Northern Snakehead* Channa argus *(Actinopterygii, Perciformes) in the Potomac River catchment*. Hydrobiologia 709:73-87.

Larson, E.R., and J.D. Olden. 2011. *The state of crayfish in the Pacific Northwest*. Fisheries 36:60-73.

Larson, E.R. and J.D. Olden. 2008. *Do schools and golf courses represent emerging pathways for crayfish invasions*? Aquatic Invasions 3:465-468.

Levine, J.M. 2000. *Species diversity and biological invasions: Relating local process to community pattern*. Science 288:852-854.

Litvak, M.K., and N.E. Mandrak. 1993. *Ecology of freshwater baitfish use in Canada and the United States*. Fisheries 18:6-13.

Liu, X., M.E. McGarrity, C. Bai, Z. Ke, and Y. Li. 2013. *Ecological knowledge reduces religious release of invasive species*. Ecosphere 4:1-12.

Lodge, D.M., S. Williams, H.J. MacIsaac, K.R. Hayes, B.Leung, S. Reichard, R.N. Mack, P.B. Moyle, M. Smith, D.A. Andow, J.T. Carlton, and A. McMichael. 2006.

Biological invasions: Recommendations for U.S. policy and management. Ecological Applications 16: 2035-2054.

Love, J.W. and J.J. Newhard. 2012. *Will the expansion of northern snakehead negatively affect the fishery for largemouth bass in the Potomac River (Chesapeake Bay)?* North American Journal of Fisheries Management 32:859-868.

Maki, K. and S. Galatowitsch. 2004. *Movement of invasive aquatic plants into Minnesota (USA) through horticultural trade*. Biological Conservation 118:389-396.

McCann, J.A. 1984. "Involvement of the American Fisheries Society with exotic species, 1969-1982." Pages 1-7 *in* W.R. Courtenay, Jr. and Jay R. Stauffer, Jr. (editors). *Distribution, Biology, and Management of Exotic Fishes*. The Johns Hopkins University Press, Baltimore, MD.

Modin, J. 1998. *Whirling disease in California: A review of its history, distribution, and impacts, 1965-1997*. Journal of Aquatic Animal Health 10:132-142.

Moser, F.C. 2002. *Invasive Species in the Chesapeake Bay Watershed: A Workshop to Develop Regional Invasive Species Management Strategies*. Final Report to the Chesapeake Bay Program, Invasive Species Working Group. Maryland Sea Grant, College Park, MD. www.mdsg.umd.edu/exotics.

Moyle, P.B. 1976. *Fish introductions in California: History and impact on native fishes*. Biological Conservation 9:101-117.

Moyle, P.B. 1986. *Fish introductions into North America: Patterns and ecological impact*. Ecology of Biological Invasions of North America and Hawaii Ecological Studies 58: 27-43.

Moyle, P.B. and T. Light. 1996. *Biological invasions of fresh water: Empirical rules and assembly theory*. Biological Conservation 78:149-161.

MPA 2014. *2014 Foreign Commerce Statistical Report*. Prepared by the Maryland Port Administration, Baltimore, Maryland.

Najjar, R.G., C.R. Pyke, M.B. Adams, D. Breitburg, C. Hershner, M. Kemp, R. Howarth, M.R. Mullholland, M. Paolisso, D. Secor, K. Sellner, D. Wardrop, and R. Wood. 2010. *Potential climate-change impacts on the Chesapeake Bay*. Estuarine, Coastal and Shelf Science 86:1-20.

NISC (National Invasive Species Council). 2008. *2008 - 2012 National Invasive Species Management Plan*. Washington, D.C., http://www.invasivespeciesinfo.gov /council/mp2008.pdf.

Naylor, R.L., S.L. Williams, and D.R. Strong. 2001. *Aquaculture- A gateway for exotic* *species*. Science 294:1655-1656.

Nicholls, K.H., S.J. Standke, and G.J. Hopkins. 1999. "Effects of dreissenid mussels on nitrogen and phosphorus in north shore waters of Lake Erie." Pages 323-336 *in* Munawar, M., T. Edsall, and I.F. Munaware (editors). *State of Lake Erie – Past, Present and Future, Ecovision World Monograph Series*. Backhuys Publishers, the Netherlands.

Orr, R., A.S. Green, and R. Lunkens. 2005. *Focus Group Conference Report and Pathways Ranking Guide*. National Invasive Species Council and Aquatic Nuisance Species Task Force, www.invasivespeciesinfo.gov.

Orth, R.J. and K.A. Moore. 1983. *Chesapeake Bay: An unprecedented decline in submerged aquatic vegetation*. Science 222:51-53.

Padilla, D.K. and S.L. Williams. 2004. *Beyond ballast water: aquarium and ornamental trades as sources of invasive species in aquatic ecosystems*. Front Ecol Environ 2:131-138.

Philipp, D.P., J.E. Claussen, T.W. Kassler, and J.M. Epifanio. 2002. "Mixing stocks of largemouth bass reduces fitness through outbreeding depression." Pages 349-364 *in*: D.P. Philipp and Ridgway (editors). *Black Bass: Ecology, Conservation, and Management*. American Fisheries Society Symposium 31, Bethesda, MD.

Philipp, D.P., W.F. Childers, and G.S. Whitt. 1983. *A biochemical genetic evaluation of the northern and Florida subspecies of largemouth bass*. Transactions of the American Fisheries Society 112:1-20.

Pimentel, D., R. Zuniga, and D. Morrison. 2005. *Update on the environmental and economic costs associated with alien-invasive species in the United States*. Ecological Economics 52: 273-288.

Radonski, G.C., N.S. Prosser, R.G. Martin, and R.H. Stroud. 1984. "Exotic fishes and sportfishes." Pages 313-321 *in* W.R. Courtenay, Jr. and J.R. Stauffer, Jr. (editors). *Distribution, Biology, and Management of Exotic Fishes*, Johns Hopkins Press, CA.

Rahel, F.J. 2000. *Homogenization of fish faunas across the United States*. Science 288: 854-856.

Rahel, F.J. and J.D. Olden. 2008. *Assessing the effects of climate change on aquatic invasive species*. Conservation Biology 22:521-533.

Reynolds, S.E. 2013. *Immunity and invasive success*. Science 340:816-817.

Ricciardi, A. 2005. "Facilitation and synergistic interactors between introduced aquatic species." Pages 162-178 *in*: H.A. Mooney (editor). *Invasive Alien Species: A New Synthesis*. Island Press, Washington D.C.

Richardson, D.M. and P. Pysek. 2011. *Fifty Years of Invasion Ecology: The Legacy of Charles Elton*. Wiley-Blackwell Publishers, Boston, MA.

Ruiz, G., J. Carlton, E. Grosholz, and A.H. Hines. 1997. *Global invasions of marine and estuarine habitats by non-indigenous species: Mechanisms, extent, and consequences*. American Zoology 37:621-632.

Sakai, A.K. and 14 others. 2001. *The population biology of invasive species*. Annual Review of Ecology and Systematics 32:305-332.

Sala, O. F.S.Chapin III, J.J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L.F. Huenneke, R.B. Jackson, A. Kinzig, R. Leemans, D.M. Lodge, H.A. Mooney, M. Oesterheld, N.L. Poff, M.T. Sykes, B.H. Walker, M. Walker, and D.H. Wall. 2000. *Global biodiversity scenarios for the year 2100*. Science 287:1770-1774.

Saylor, R.K., N.W.R. Lapointe, and P.L. Angermeier. 2012. *Diet of non-native northern snakehead (*Channa argus*) compared to three co-occurring predators in the lower Potomac River, USA*. Ecology of Freshwater Fish 21:443-452.

Schofield, P.J. 2009. *Geographic extent and chronology of the invasion of non-native lionfish (*Pterois volitans *[Linnaeus 1758] and* P. miles *[Bennett 1828] in the western North Atlantic and Caribbean Sea*. Aquatic Invasions 4:473-479.

Shafland, P.L. and J.M. Pestrak. 1982. *Lower lethal temperatures for fourteen non-native fishes in Florida*. Environmental Biology of Fishes 7:149-156.

Shafland, P.L. 1996. *Exotic fish assessments: An alternative view*. Reviews in Fisheries Science 4:123-132.

Shiu, H., and L. Stokes. 2009. *Buddhist animal release practices: Historic, environmental, public health, and economic concerns*. Contemporary Buddhism 9:181-196.

Smith, B.R. and J.J. Tibbles. 1980. *Sea lamprey (*Petromyzon marinus*) in Lakes Huron, Michigan, and Superior: History of invasion and control, 1936-78*. Canadian Journal of Fisheries and Aquatic Sciences 37:1780-1801.

Smits, J. and F. Moser. 2009. *Rapid Response Planning for Aquatic Invasive Species: A Template*. Mid-Atlantic Panel on Aquatic Invasive Species. National Oceanic and Atmospheric Administration, Publication Number UM-SG-TS-2009-01.

Spataru, P. and M. Gophen. 1985. *Feeding behavior of silver carp* Hypophthalmichthys molitrix *Val. and its impact on the food web in Lake Kinneret, Israel*. Hydrobiologia 120:53-61.

Stranko, S.A., D.C. Forester, and J.V. Kilian. 2003. *Discovery of the Jefferson salamander,* Ambystoma jeffersonianum *(Green), east of the Blue Ridge mountains, in Frederick and Montgomery County, Maryland*. The Maryland Naturalist 46:41-46.

Strecker, A.L., P.M. Campbell, and J.D. Olden. 2011. *The aquarium trade as an invasion pathway in the Pacific Northwest*. Fisheries 36:74-85.

Thomas, M.E. 1993. *Monitoring the effects of introduced flathead catfish on sport fish populations in the Altamaha River, Georgia*. Proceedings of the Annual Conference of Southeastern Association of Fish and Wildlife Agencies 47:531-538.

Tyus, H.M. and J.F. Saunders, III. 2000. *Nonnative fish control and endangered fish recovery: Lessons from the Colorado River*. Fisheries 25:17-24.

USGS (United States Geological Survey). 2014. *Nonindigenous Aquatic Species Database*. http://nas.usgs.gov. Accessed March 20, 2014.

Vander Zanden, M. J. and J.D. Olden. 2008. *A management framework for preventing the secondary spread of aquatic invasive species*. Canadian Journal of Fisheries and Aquatic Science 65:1512-1522.

Verbrugge, L.N.H., G. van der Velde, A.J. Hendriks, H. Verreycken, and R.S.E.W. Leuven. 2012. *Risk classifications of aquatic non-native species: Application of contemporary European assessment protocols in different biogeographical settings*. Aquatic Invasions 7:49-58.

Vitousek, P.M, C.M. D'Antonio, L.L. Loope, and R. Westbrooks. 1996. *Biological invasions as global environmental change*. American Scientist 84:468-478.

Vitule, J.R.S., C.A. Freire, and D. Simberloff. 2009. *Introduction of non-native freshwater fish can certainly be bad*. Fish and Fisheries 10:98-108.

Westhoff, J.T. and T.A. Kobermann. 2015. *Prevalence of aquatic introduced species prevention protocols at U.S. college and university fisheries programs*. Fisheries 40: 513-519.

Whitehead, A.J. and G. Orriss. 2015 (accessed). *Food safety through HACCP - The FAO approach*. Food and Agriculture Organization, http://www.fao.org/docrep/v9723t/v9723t0e.htm.

Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips, and E. Losos. 1998. *Quantifying threats to imperiled species in the United States: Assessing the relative importance of* *habitat destruction, alien species, pollution, overexploitation, and disease*. Bioscience 48:607-615.

Wood, B.R., D.F. Boesch, and V.S. Kennedy. 2002. *Future consequences of climate change for the Chesapeake Bay ecosystem and its fisheries*. American Fisheries Society Symposium 32:171-184.

Maryland Aquatic Nuisance Species Management Plan

APPENDICES

Appendix 1: RANKING SPECIES AS ANS

Appendix 2: EXISTING AUTHORITIES AND PROGRAMS

Appendix 3: HISTORY OF PLAN DEVELOPMENT

Appendix 4: PUBLIC COMMENTS ON ANS PLAN

Appendix 1. RANKING SPECIES AS ANS

Ranking Aquatic Species as ANS

Non-native species that may be or are currently distributed in Maryland because of direct or indirect introductions by humans. This is an incomplete list and will be updated with new information as it becomes available. A rank prioritizes each species for its level of concern: Red Alert (RED), High (HIGH), Low (LOW), Unknown (UNK). Species ranked as high priority or red alert are considered aquatic nuisance species or ANS. i = introduction, not established; e = established population; nr = not reported in Maryland. Data updated at: http://dnr.state.md.us/invasives.

Scientific Name	Common Name	Status	Rank
AQUATIC & WETLAND MACROPHYTES			
Aldrovanda vesiculosa	waterwheel	nr	HIGH
Butomus umbellatus	flowering rush	i	LOW
Cabomba caroliniana	fanwort	i	LOW
Callitriche stagnalis	pond water-starwort	i	LOW
Didymosphenia geminata	didymo	e	HIGH
Egeria densa	Brazilian elodea	e	HIGH
Eichhornia crassipes	common water-hyacinth	e	RED
Glyceria maxima	English water grass	i	LOW
Hydrilla verticillata	Hydrilla	e	HIGH
Hydrocharis morus-ranae	European frog-bit	i	LOW
Hygrophila polysperma	East Indian hygrophila	i	LOW
Iris pseudacorus	yellow iris	i	LOW
Lythrum salacaria and cultivars	purple loosestrife	e	HIGH
Marsilea quadrifolia	European waterclover	i	LOW
Murdannia keisak	marsh dayflower	e	HIGH
Myriophyllum aquaticum	parrot feather	e	HIGH
Myriophyllum heterophyllum	variable milfoil	i	LOW
Myriophyllum spicatum	Eurasian milfoil	e	HIGH
Najas minor	European naiad	i	LOW
Nymphoides peltata	yellow floating-heart	i	LOW
Phragmitis australis	common reed	e	HIGH
Pistia stratiotes	water lettuce	i	LOW
Rorippa microphylla	onerow yellowcress	i	LOW
Rorippa nasturtium-aquaticum	watercress	i	LOW
Salvinia molesta	giant salvinia	e	RED
Trapa natans	water chestnut	e	HIGH
ALGAE			
Caulerpa taxifolia	caulerpa	n	LOW
Porphyra yezoensis	nori	i	LOW

FISH

Astronotus ocellatus	oscar	i	LOW
Channa argus	northern snakehead	e	HIGH
Channa micropeltes	giant snakehead	i	UNK
Cichla ocellaris	butterfly peacock bass	i	LOW
Clarius batrachus	walking catfish	nr	LOW
Coregonas artedi	cisco	i	LOW
Ctenopharyngodon idella	grass carp	i	LOW
Cyprinus auratus	goldfish	e	LOW
Cyprinus carpio	common carp	e	LOW
Esox lucius x *masquinongy*	tiger muskellunge	i	LOW
Esox lucius	northern pike	e	LOW
Esox masquinongy	muskellunge	i	LOW
Ethoestoma zonale	banded darter	e	LOW
Hiodon tergisus	mooneye	i	LOW
Hypophthalmichthys molitrix	silver carp	nr	RED
Hypophthalmichthys nobilis	bighead carp	nr	RED
Ictalurus furcatus	blue catfish	e	HIGH
Ictalurus punctatus	channel catfish	e	LOW
Lepomis macrochirus	bluegill	e	LOW
Lepomis megalotis	longear sunfish	e	LOW
Lepomis microlophus	redear sunfish	e	LOW
Leuciscus idus	orfe	e	LOW
Micropterus dolomieu	smallmouth bass	e	UNK
Micropterus salmoides	largemouth bass	e	LOW
Misgurnus anguillcaudatus	oriental weatherfish	e	UNK
Monoterus albus	Asian swamp eel	i	RED
Morone chrysops x *saxatilis*	wiper	i	LOW
Morone chrysops	white bass	i	LOW
Mylopharyngodon piceus	black carp	i	UNK
Neogobius melanostomus	round goby	nr	RED
Notropis atherinoides	emerald shiner	e	LOW
Notropis volucellus	mimic shiner	e	LOW
Oncorhynchus clarkia behnkei	snakeriver cutthroat trout	i	LOW
Oncorhynchus clarkia	cutthroat trout	i	LOW
Oncorhynchus gorbuscha	pink salmon	i	LOW
Oncorhynchus kisutch	coho salmon	i	LOW
Oncorhynchus mykiss	rainbow trout	e	LOW
Oncorhynchus tshawytscha	chinook salmon	i	LOW
Osmerus mordax	rainbow smelt	i	LOW
Piractus brachypomus	pacu	i	LOW
Pomoxis annularis	white crappie	e	LOW
Proterothinus marmoratus	tubenose goby	i	LOW
Pterois voltans	lionfish	nr	RED
Pterois miles	lionfish	nr	RED

Pylodictus olivaris	flathead catfish	e	HIGH
Pygocentrus spp.; *Serrasalmus* spp.	piranha	i	LOW
Salmo salar	Atlantic salmon	i	LOW
Salmo trutta	brown trout	e	LOW
Salvelinus fontinalis x namaycush	splake	i	LOW
Salvelinus namacush	lake trout	i	LOW
Scardinius erythrophthalmus	rudd	i	LOW
Tinca tinca	tench	e	LOW

MOLLUSCANS

Cipangopaludina chivesis	Chinese mystery snail	e	UNK
Dreissena bugensis	quagga mussel	nr	UNK
Dreissena polymorpha	zebra mussel	e	HIGH
Crassostrea gigas	Pacific oyster L**	i	UNK
Potamophygrus antipodarum	New Zealand mud snail	nr	RED
Rapana venosa	veined rapa whelk	nr	LOW

CRUSTACEANS

Bythotrephes cederstoemi	spiny waterflea	nr	UNK
Cambarus thomai	little brown mudbug	e	LOW
Carcinus maenas	green crab	e	HIGH
Cercopagis pengoi	fishhook waterflea	i	UNK
Cherax spp.	Australian crayfish	nr	UNK
Daphnia lumholtzi	Daphnia	nr	UNK
Eriocheir sinensis	Chinese mitten crab	e	HIGH
Hemigrapsus sanguineus	Japanese shore crab	e	HIGH
Mysis relicta	opossum shrimp	i	LOW
Orconectes rusticus	rusty crayfish	e	HIGH
Orconectes virilis	virile crayfish	e	HIGH
Procambrus clarkii	red swamp crawfish	e	HIGH
Tachypleus spp.	Asian horseshoe crab	i	RED

FISH PATHOGENS

Bothriocephalus acheilognathi	Asian tapeworm	e	LOW
Myxobolus cerebralis	whirling disease	i	HIGH
Proteocephalus amblopltis	bass tapeworm	e	LOW
VHS	viral hemorrhagic septicemia	nr	UNK

REPTILIA

Trachemys scrypta elegans	red eared slider turtle	e	LOW
Trachemys scripta scripta	yellow-bellied slider	e	LOW
Graptemys pseudogeographica	false map turtle	e	LOW

AVES

Branta canadensis	resident Canada goose	e	HIGH
Cygnus olor	mute swan	e	HIGH

MAMMALS

Myocaster coypus	nutria	e	HIGH
Sus scrofa	feral swine	nr	RED

Appendix 2: EXISTING AUTHORITIES AND PROGRAMS

TO BE COMPLETED

Appendix 3. HISTORY OF ANSP DEVELOPMENT

TO BE COMPLETED

Appendix 4. PUBLIC COMMENTS ON THE ANSP

Public Comments on the ANSP

Public comments were received on the ANSP during winter and spring of 2016. It was opened on 12/24/2015. A notice was sent out using Constant Contact to the general public who had signed up to receive notices from Maryland Department of Natural Resources. It was also posted on the Department's Invasive Species Matrix Page. A copy was supplied to commissioners of the Sport Fish Advisory Commission and the Tidal Fish Advisory Commission, which represent commercial and recreational angler interests in Maryland. The date and initials of commenter are provided along with the unaltered comment.

B.C. 12/28/2015

I'm a Maryland recreational angler. I'm retired, but during my working life, I acquired an environmental background. Very good plan. Well done. My comments are below.

Comments on Maryland Aquatic Nuisance Species Management Plan - draft dated December 2015

Page 5. In the Executive Summary, consider qualifying or in some way quantifying the term "Chesapeake Bay watershed" so that it better defines the scope of the plan, otherwise begin the sentence with, "For example, in the Chesapeake Bay watershed . . . ." To the casual reader or layperson quickly reading the executive summary, it seems that the plan may only be addressing the Bay and nearby waters/adjacent tributaries.

Page 6. The Objectives, and the Actions to Achieve Objections are very good. They appear to be both comprehensive and executable.

Page 10. In the Glossary, consider adding the term, "Non-native non-nuisance" or Non-indigenous non-nuisance in order to define those species that although not native to the state, have been long established, are naturally reproducing in such a way that wild populations of the species exist, and have become in many ways a beneficial part of the current ecosystem.

Page 12. In the Acronyms, you may want to include NOAA.

Page 19, second paragraph. The period needs to be removed at the end of the sentence that reads, "The USCG also regulates ballast water discharge in United States waters under the United States.", or the following needs to be added, ". . . Code of Federal Regulations, Title 46, Shipping." or something to that effect.

Page 24, Angler Gear Pathway. I would like to comment, and it may be noteworthy to add that the ban on the use of felt soled wading boots in Maryland waters comes at an increased fall risk to the angler. Pennsylvania has not yet instituted this ban, at least not to my knowledge. It may be worthwhile to find out how their plan addresses the angler gear pathway with respect to wading boots, and if adequate, adopt it for Maryland waters?

Page 46. General comment related to Plan Strategies 3. I am in favor of the plan, as long as an attempt is not made to eradicate "non-native non-nuisance" species in order to better establish or re-establish "genetically pure" native species. As explained in the plan, many non-native species were introduced with good intention, only to discover their negative impacts after the fact. I know it's unlikely to happen given current requirements to conduct environmental assessments prior to taking action, but please avoid the pitfall of committing two wrongs in order to make a right especially at taxpayer expense.

Good luck to the working group/committee, keep up the good work, and thank you for the opportunity to comment.

J.O. 12/26/2015

1) The statement on page 25 that "…Blue Catfish and Flathead Catfish were introduced for sport fishing in the Potomac River in the 1960s by VDGIF" is false and should be removed or edited. VDGIF has NEVER stocked blue catfish in the Potomac River for any purpose. We stocked several Virginia rivers in the 1970s, and as I think you know; the origin of BCF in the tidal Potomac is unknown. To deliberately indict VDGIF for this introduction is grossly misleading and disingenuous. Flatheads were stocked in the Occoquan in the 1960s. This misrepresentation is repeated on page 29 and should be changed.

2) I am uncertain how you (or others) determined that Northern Snakehead have a "high probability of negative economic and/or ecological impacts". As I thought you knew, there are no published accounts of anything of the sort. The two studies cited in the draft merely show dietary overlap (not competition as claimed) and the fact that snakeheads will eat bass fingerlings when starved in hatchery raceways. I think one could actually argue that at this point there have been economic benefits of this fish, although I would not advertise it.

3) The Flathead Catfish section appears to suggest these fish colonized the Susquehanna system by dispersing from the Occoquan. This should be revised to reflect reality including the very low abundance of this fish in the tidal Potomac system and the near impossibility that they seeded other bay populations. That this fish was such a nuisance, DNR requested to sample Virginia waters (unsuccessfully) just to find one to display at the state fair. Don't really see that problem…